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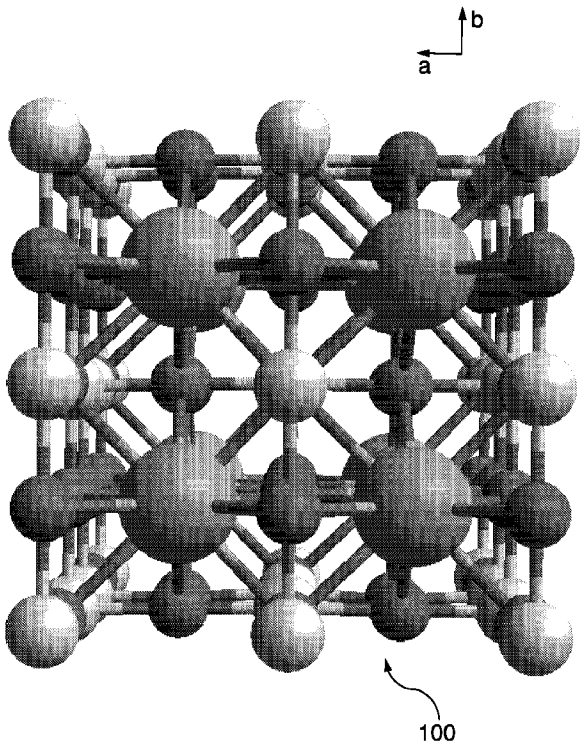
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(72) Inventeurs/Inventors:
GILBERT, DOUGLAS J., US;
SHTEYN, YEVGENIY EUGENE, US;
SMITH, MICHAEL J., US;
HANNA, JOEL PATRICK, US;
GREENLAND, PAUL, US;

(54) Titre : DISPOSITIFS ELECTRIQUES, MECANIQUES, INFORMATIQUES, ET/OU AUTRES DISPOSITIFS CONSTITUES DE MATERIAUX A RESISTANCE EXTREMEMENT FAIBLE

(54) Title: ELECTRICAL, MECHANICAL, COMPUTING, AND/OR OTHER DEVICES FORMED OF EXTREMELY LOW RESISTANCE MATERIALS



(57) Abrégé/Abstract:
Electrical, mechanical, computing, and/or other devices that include components formed of extremely low resistance (ELR) materials, including, but not limited to, modified ELR materials, layered ELR materials, and new ELR materials, are described.

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(72) Inventeurs(suite)/Inventors(continued): COPPA, BRIAN, US; NORTH, FORREST, US

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(54) Title: ELECTRICAL, MECHANICAL, COMPUTING, AND/OR OTHER DEVICES FORMED OF EXTREMELY LOW RESISTANCE MATERIALS

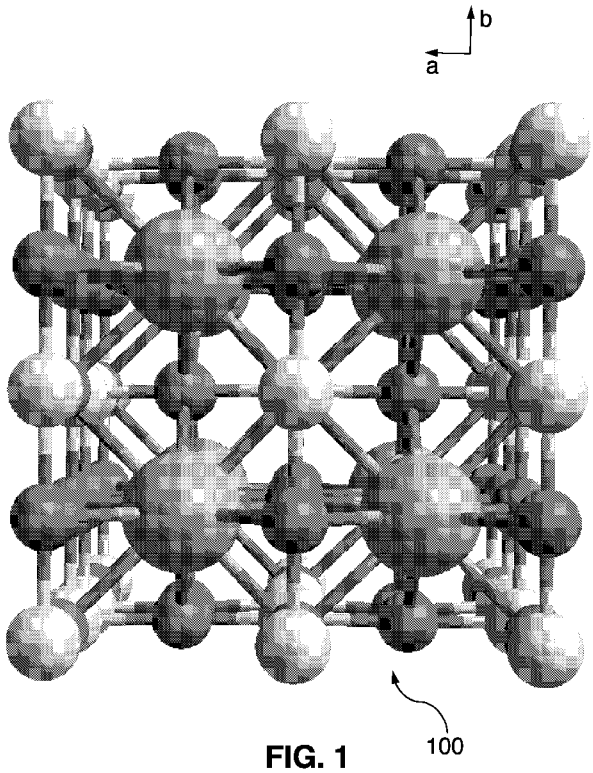


FIG. 1

(57) Abstract: Electrical, mechanical, computing, and/or other devices that include components formed of extremely low resistance (ELR) materials, including, but not limited to, modified ELR materials, layered ELR materials, and new ELR materials, are described.

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61/469,727	30 March 2011 (30.03.2011)	US	61/469,772	30 March 2011 (30.03.2011)	US
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[Continued on next page]

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(71) **Applicant** *(for all designated States except US)*: **AMBATURE LLC** [US/US]; 506 N. Grant Street, Flagstaff, AZ 86004-6024 (US).

(72) **Inventors; and**

(75) **Inventors/Applicants** *(for US only)*: **GILBERT, Douglas, J.** [US/US]; C/o Ambature LLC, 506 N. Grant Street, Flagstaff, AZ 86004-6024 (US). **SHTEYN, Yevgeniy, Eugene** [US/US]; C/o Ambature LLC, 506 N. Grant Street, Flagstaff, AZ 86004-6024 (US). **SMITH, Michael, J.** [US/US]; C/o Ambature LLC, 506 N. Grant Street, Flagstaff, AZ 86004-6024 (US). **HANNA, Joel, Patrick** [US/US]; C/o Ambature LLC, 506 N. Grant Street, Flagstaff, AZ 86004-6024 (US). **GREENLAND, Paul** [GB/US]; C/o Ambature LLC, 506 N. Grant Street, Flagstaff, AZ 86004-6024 (US). **COPPA, Brian** [US/US]; C/o Ambature LLC, 506 N. Grant Street, Flagstaff, AZ 86004-6024 (US). **NORTH, Forrest** [US/US]; C/o Ambature LLC, 506 N. Grant Street, Flagstaff, AZ 86004-6024 (US).

(74) **Agent**: **TOERING, Rick, A.**; Womble Carlyle Sandridge & Rice, LLP, P.O. Box 7037, Atlanta, GA 30357-0037 (US).

(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

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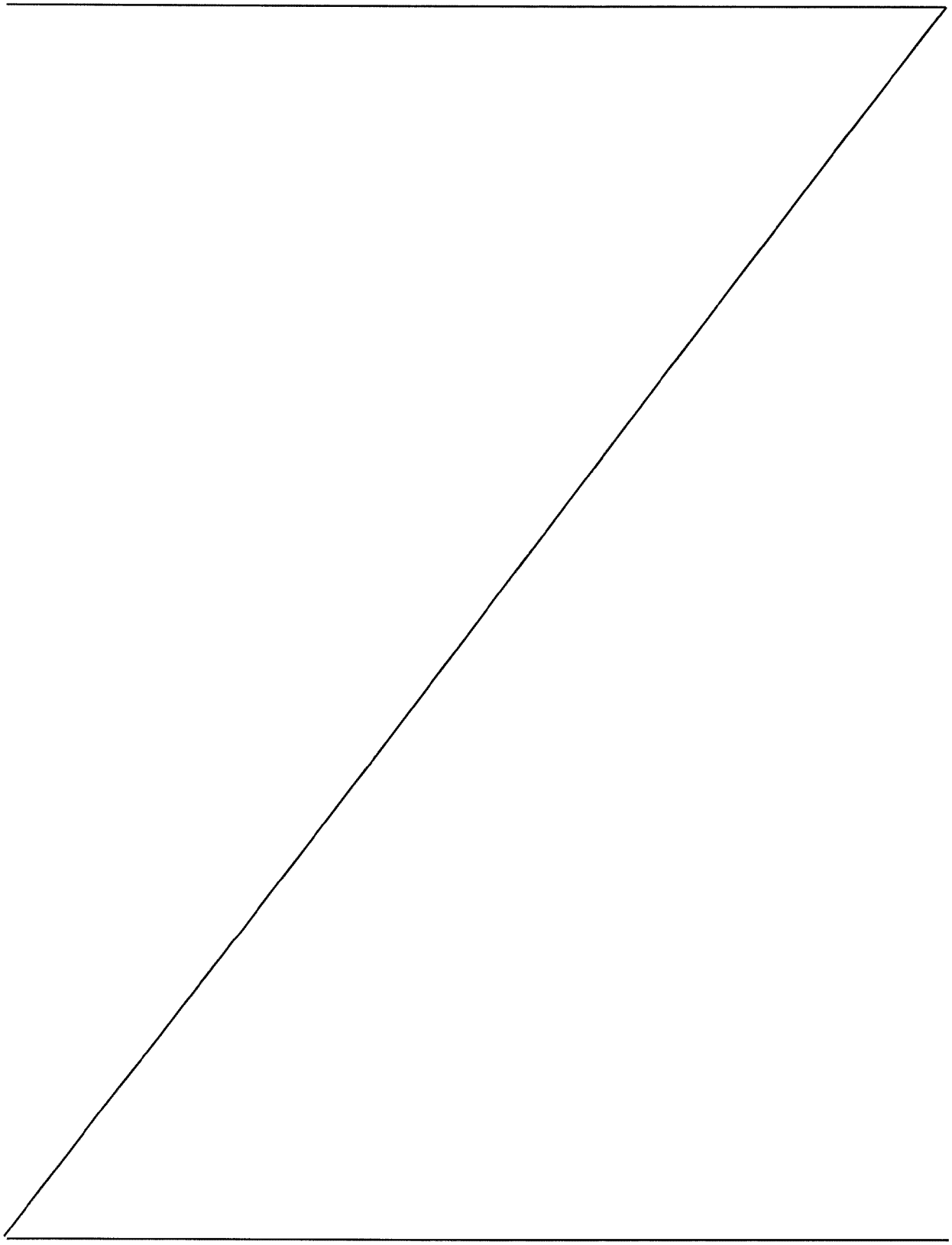
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ELECTRICAL, MECHANICAL, COMPUTING, AND/OR OTHER DEVICES FORMED OF EXTREMELY LOW RESISTANCE MATERIALS

[0001] The present invention relates to electrical, mechanical, computing, and/or other devices, components, systems, and/or apparatuses that include one or more components formed of modified, apertured, layered, and/or other new extremely low resistance (ELR) materials, are described. The ELR materials provide extremely low resistances to current at temperatures higher than temperatures normally associated with current high temperature superconductors (HTS), enhancing the operational characteristics of the devices at these higher temperatures, among other benefits.



[0002] BACKGROUND

[0003] Electrical, mechanical, computing, and/or other devices that operate using conventional superconducting elements suffer from various drawbacks, including the reliance on expensive cooling systems to maintain the superconducting elements in their superconducting states. For example, conventional superconducting capacitors utilize high temperature superconducting (HTS) materials for various components, relying on their ability to transfer current with minimal or zero resistance to the current. However, HTS materials require very low operating temperatures (e.g., temperatures under 120K) typically realized by cooling the components to such temperatures using expensive systems, such as liquid nitrogen-based cooling systems. Such cooling systems increase implementation costs and discourage widespread commercial and consumer use and/or application of capacitors that employ these materials. These and other problems exist with respect to current HTS-based devices.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] Figure 1 illustrates a crystalline structure of an exemplary ELR material as viewed from a first perspective.

[0005] Figure 2 illustrates a crystalline structure of an exemplary ELR material as viewed from a second perspective.

[0006] Figure 3 illustrates a crystalline structure of an exemplary ELR material as viewed from a second perspective.

[0007] Figure 4 illustrates a single unit cell of an exemplary ELR material.

[0008] Figure 5 illustrates a crystalline structure of an exemplary ELR material as viewed from a second perspective.

[0009] Figure 6 illustrates a crystalline structure of an exemplary ELR material as viewed from a second perspective.

[0010] Figure 7 illustrates a crystalline structure of an exemplary ELR material as viewed from a second perspective.

[0011] Figure 8 illustrates a crystalline structure of an exemplary ELR material as viewed from a second perspective.

[0012] Figure 9 illustrates a crystalline structure of an exemplary ELR material as viewed from a second perspective.

[0013] Figure 10 illustrates a modified crystalline structure, according to various implementations of the invention, of an ELR material as viewed from a second perspective.

[0014] Figure 11 illustrates a modified crystalline structure, according to various implementations of the invention, of an ELR material as viewed from a first perspective.

[0015] Figure 12 illustrates a crystalline structure of an exemplary ELR material as viewed from a third perspective.

[0016] Figure 13 illustrates a reference frame useful for describing various implementations of the invention.

[0017] Figures 14A-14G illustrate test results demonstrating various operational characteristics of a modified ELR material.

[0018] Figure 15 illustrates test results for a modified ELR material, namely with chromium as a modifying material and YBCO as an ELR material.

[0019] Figure 16 illustrates test results for a modified ELR material, namely with vanadium as a modifying material and YBCO as an ELR material.

[0020] Figure 17 illustrates test results for a modified ELR material, namely with bismuth as a modifying material and YBCO as an ELR material.

[0021] Figure 18 illustrates test results for a modified ELR material, namely with copper as a modifying material and YBCO as an ELR material.

[0022] Figure 19 illustrates test results for a modified ELR material, namely with cobalt as a modifying material and YBCO as an ELR material.

[0023] Figure 20 illustrates test results for a modified ELR material, namely with titanium as a modifying material and YBCO as an ELR material.

[0024] Figures 21A-21B illustrate test results for a modified ELR material, namely with chromium as a modifying material and BSCCO as an ELR material.

[0025] Figure 22 illustrates an arrangement of an ELR material and a modifying material useful for propagating electrical charge according to various implementations of the invention.

[0026] Figure 23 illustrates multiple layers of crystalline structures of an exemplary surface-modified ELR material according to various implementations of the invention.

[0027] Figure 24 illustrates a c-film of ELR material according to various implementations of the invention.

[0028] Figure 25 illustrates a c-film with appropriate surfaces of ELR material according to various implementations of the invention.

[0029] Figure 26 illustrates a c-film with appropriate surfaces of ELR material according to various implementations of the invention.

[0030] Figure 27 illustrates a modifying material layered onto appropriate surfaces of ELR material according to various implementations of the invention.

[0031] Figure 28 illustrates a modifying material layered onto appropriate surfaces of ELR material according to various implementations of the invention.

[0032] Figure 29 illustrates a c-film with an etched surface including appropriate surfaces of ELR material according to various implementations of the invention.

[0033] Figure 30 illustrates a modifying material layered onto an etched surface of a c-film with appropriate surfaces of ELR material according to various implementations of the invention.

[0034] Figure 31 illustrates an a-b film, including an optional substrate, with appropriate surfaces of ELR material according to various implementations of the invention.

[0035] Figure 32 illustrates a modifying material layered onto appropriate surfaces of ELR material of an a-b film according to various implementations of the invention.

[0036] Figure 33 illustrates various exemplary arrangements of layers of ELR material, modifying material, buffer or insulating layers, and/or substrates in accordance with various implementations of the invention.

[0037] Figure 34 illustrates a process for forming a modified ELR material according to various implementations of the invention.

[0038] Figure 35 illustrates an example of additional processing that may be performed according to various implementations of the invention.

[0039] Figure 36 illustrates a process for forming a modified ELR material according to various implementations of the invention.

[0040] Figure 1-Z is a block diagram of a composition that includes an extremely low material component and a modifying component according to various implementations of the invention.

[0041] Figure 2-Z is a block diagram of a composition that includes an extremely low resistance material and two or more modifying components according to various implementations of the invention.

[0042] Figure 3-Z is a block diagram of a composition that includes layers of different extremely low resistance materials according to various implementations of the invention.

[0043] Figure 4-Z is a block diagram of a composition that includes layers of different forms of the same extremely low resistance material according to various implementations of the invention.

[0044] Figure 5-Z is a block diagram of a composition that includes multiple layers of different extremely low resistance materials according to various implementations of the invention.

[0045] Figure 6-Z is a block diagram of an exemplary composition that includes multiple layers of extremely low resistance materials according to various implementations of the invention.

[0046] Figures 7A-Z to 7I-Z include test results demonstrating various operational characteristics of the exemplary composition illustrated in Figure 6-Z.

[0047] Figures 37-A to 45B-A illustrate the forming of nanowires using ELR materials.

[0048] Figures 46-A to 46J-A illustrate the forming of Josephson Junctions (JJs) using ELR materials.

[0049] Figures 47-A to 53-A illustrate the forming of SQUIDs using ELR materials.

[0050] Figures 54-A to 59-A illustrate the forming of medical devices using ELR materials.

[0051] Figures 37A-B to 43-B illustrate the forming of capacitors using ELR materials.

[0052] Figures 37-C to 43-C illustrate the forming of inductors using ELR materials.

[0053] Figures 37-D to 44-D illustrate the forming of transistors using ELR materials.

[0054] Figures 37-E to 45-E illustrate the forming of integrated circuit devices using ELR materials.

[0055] Figures 37-F to 45-F illustrate the forming of integrated circuits and MEMS devices using ELR materials.

[0056] Figures 37-G to 41-G illustrate the forming of integrated circuit RF devices using ELR materials.

[0057] Figures 37-H to 43-H illustrate the forming of integrated circuit routing components and devices using ELR materials.

[0058] Figures 37-I to 41B-I illustrate the forming of integrated circuit SiP devices using ELR materials.

[0059] Figures 37A-J to 42-J illustrate the forming of rotating machines using ELR materials.

[0060] Figures 37A-K to 41-K illustrate the forming of bearings using ELR materials.

[0061] Figures 37-L to 88-L illustrate the forming of sensors using ELR materials.

[0062] Figures 37-M to 50-M illustrate the forming of actuators using ELR materials.

[0063] Figures 37-N to 50-N illustrate the forming of filters using ELR materials.

[0064] Figures 37-O to 56-O illustrate the forming of antennas using ELR materials.

[0065] Figures 37-P to 43-P illustrate the forming of energy storage devices using ELR materials.

[0066] Figures 37-Q to 50-Q illustrate the forming of fault current limiters using ELR materials.

[0067] Figures 37-R to 50-R illustrate the forming of transformers using ELR materials.

[0068] Figures 37A-S to 40B-S illustrate the forming of transmission lines using ELR materials.

DETAILED DESCRIPTION

[0069] Electrical, mechanical, computing, and/or other devices, components, systems, and/or apparatuses that include one or more components formed of modified, apertured, layered, and/or other new extremely low resistance (ELR) materials, are described. The ELR materials provide extremely low resistances to current at temperatures higher than temperatures normally associated with current high temperature superconductors (HTS), enhancing the operational characteristics of the devices at these higher temperatures, among other benefits.

[0070] In some examples, the ELR materials are manufactured based on the type of materials, the application of the ELR materials, the size of the component employing the ELR materials, the operational requirements of a device or machine employing the ELR materials, and so on. As such, during the design and manufacturing of a device, the material used as a base layer of an ELR material and/or the material used as one or more modifying layers of the ELR material may be selected based on various considerations and desired operating and/or manufacturing characteristics.

[0071] Various devices, applications, and/or systems may employ the ELR components described herein. These devices, applications, and/or systems will be discussed in greater detail in Chapters 1 – 18 of this application.

[0072] The technology will now be described with respect to various examples and/or embodiments. The following description provides specific details for a thorough understanding of, and enabling description for, these examples of the system. However, one skilled in the art will understand that the system may be practiced without these details. In other instances, well-known structures and functions have not been shown or

described in detail to avoid unnecessarily obscuring the description of the examples of the system.

[0073] The terminology used in the description presented below is intended to be interpreted in its broadest reasonable manner, even though it is being used in conjunction with a detailed description of certain specific embodiments of the system. Certain terms may even be emphasized below; however, any terminology intended to be interpreted in any restricted manner will be overtly and specifically defined as such in this Detailed Description section.

[0074] Various features, advantages, and implementations of the invention may be set forth or be apparent from consideration of the following detailed description, the drawings, and the claims. It is to be understood that the detailed description and the drawings are exemplary and intended to provide further explanation without limiting the scope of the invention except as set forth in the claims.

[0075] For purposes of this description, extremely low resistance ("ELR") materials may include: superconducting materials, including, but not limited to, HTS materials; perfectly conducting materials (e.g., perfect conductors); and other conductive materials with extremely low resistance. As discussed herein, these ELR materials may be described as modified ELR materials, apertured ELR materials and/or new ELR materials, any of which may be used to form ELR films and/or other ELR components (e.g., nanowires, wires, tapes, etc.). These ELR materials exhibit extremely low resistance to electrons and/or extremely high conductance of electrons at high temperatures, such as temperatures above 150K, at ambient or standard pressure. This section describes, among other things, the structure and operational characteristics of these ELR materials.

[0076] Generally speaking, various implementations of the invention relate to incorporating an ELR material (e.g., a modified ELR material, a new ELR material, etc.) with improved operating characteristics, or an ELR material exhibiting some or all of the improved operating characteristics described herein, into various products, systems and/or devices as described herein. Various implementations of the invention may include such ELR materials in the form of ELR films, ELR tapes, ELR nanowires, ELR wires, and other configurations of such ELR materials.

[0077] For purposes of this description, operating characteristics with regard to ELR materials and/or various implementations of the invention may include, but are not limited to, a resistance of the ELR material in its ELR state (for example, with regard to superconductors, a superconducting state), a transition temperature of the ELR material

to its ELR state, a charge propagating capacity of the ELR material in its ELR state, one or more magnetic properties of the ELR material, one or more mechanical properties of the ELR material, and/or other operating characteristics of the ELR material. Further, for purposes of this description, improved operating characteristics may include, but are not limited to, operating in an ELR state (including, for example, a superconducting state) at higher temperatures, operating with increased charge propagating capacity at the same (or higher) temperatures, operating with improved magnetic properties, operating with improved mechanical properties, and/or other improved operating characteristics.

[0078] For purposes of this description, "extremely low resistance" is resistance similar in magnitude to the flux flow resistance of Type II superconducting materials in their superconducting state, and may generally be expressed in terms of resistivity in a range of zero Ohm-cm to one fiftieth (1/50) of the resistivity of substantially pure copper at 293K. For example, as used herein, substantially pure copper is 99.999% copper. In various implementations of the invention, portions of ELR materials have a resistivity in a range of zero Ohm-cm to 3.36x10-8 Ohm-cm.

[0079] As generally understood, the transition temperature is a temperature below which the ELR material "operates" or exhibits (or begins exhibiting) extremely low resistance, and/or other phenomenon associated with ELR materials. When operating with extremely low resistance, the ELR material is referred to as being in an ELR state. At temperatures above the transition temperature, the ELR material ceases to exhibit extremely low resistance and the ELR material is referred to as being in its non-ELR or normal state. In other words, the transition temperature corresponds to a temperature at which the ELR material changes between its non-ELR state and its ELR state. As would be appreciated, for some ELR materials, the transition temperature may be a range of temperatures over which the ELR material changes between its non-ELR state and its ELR state. As would also be appreciated, the ELR material may have hysteresis in its transition temperature with one transition temperature as the ELR material warms and another transition temperature as the ELR material cools.

[0080] Figure 13 illustrates a reference frame 1300 which may be used to describe various implementations of the invention. Reference frame 1300 includes a set of axes referred to as an a-axis, a b-axis, and a c-axis. For purposes of this description: reference to the a-axis includes the a-axis and any other axis parallel thereto; reference to the b-axis includes the b-axis and any other axis parallel thereto; and reference to the c-axis includes the c-axis and any other axis parallel thereto. Various pairs of the axes

form a set of planes in reference frame 1300 referred to as an a-plane, a b-plane, and a c-plane, where: the a-plane is formed by the b-axis and the c-axis and is perpendicular to the a-axis; the b-plane is formed by the a-axis and the c-axis and is perpendicular to the b-axis; and the c-plane is formed by the a-axis and the b-axis and is perpendicular to the c-axis. For purposes of this description: reference to the a-plane includes the a-plane and any plane parallel thereto; reference to the b-plane includes the b-plane and any plane parallel thereto; and reference to the c-plane includes the c-plane and any plane parallel thereto. Further, with regard to various "faces" or "surfaces" of the crystalline structures described herein, a face parallel to the a-plane may sometimes be referred to as a "b-c" face; a face parallel to the b-plane may sometimes be referred to as an "a-c" face; and a face parallel to the c-plane may sometimes be referred to as a "a-b" face.

[0081] Figure 1 illustrates a crystalline structure 100 of an exemplary ELR material as viewed from a first perspective, namely, a perspective perpendicular to an "a-b" face of crystalline structure 100 and parallel to the c-axis thereof. Figure 2 illustrates crystalline structure 100 as viewed from a second perspective, namely, a perspective perpendicular to a "b-c" face of crystalline structure 100 and parallel to the a-axis thereof. For purposes of this description, the exemplary ELR material illustrated in Figure 1 and Figure 2 is generally representative of various ELR materials. In some implementations of the invention, the exemplary ELR material may be a representative of a family of superconducting materials referred to as mixed-valence copper-oxide perovskites. The mixed-valence copper-oxide perovskite materials include, but are not limited to, LaBaCuOx, LSCO (e.g., La2-xSrxCuO4, etc.), YBCO (e.g., YBa2Cu3O7, etc.), BSCCO (e.g., Bi2Sr2Ca2Cu3O10, etc.), TBCCO (e.g., Tl2Ba2Ca2Cu3O10 or TlmBa2Can−1CunO2n+m+2+δ), HgBa2Ca2Cu3Ox, and other mixed-valence copper-oxide perovskite materials. The other mixed-valence copper-oxide perovskite materials may include, but are not limited to, various substitutions of the cations as would be appreciated. As would also be appreciated, the aforementioned named mixed-valence copper-oxide perovskite materials may refer to generic classes of materials in which many different formulations exist. In some implementations of the invention, the exemplary ELR materials may include an HTS material outside of the family of mixed-valence copper-oxide perovskite materials ("non-perovskite materials"). Such non-perovskite materials may include, but are not limited to, iron pnictides,

magnesium diboride (MgB2), and other non-perovskites. In some implementations of the invention, the exemplary ELR materials may be other superconducting materials.

[0082] Many ELR materials have a structure similar to (though not necessarily identical to) that of crystalline structure 100 with different atoms, combinations of atoms, and/or lattice arrangements as would be appreciated. As illustrated in Figure 2, crystalline structure 100 is depicted with two complete unit cells of the exemplary ELR material, with one unit cell above reference line 110 and one unit cell below reference line 110. Figure 4 illustrates a single unit cell 400 of the exemplary ELR material.

[0083] Generally speaking and as would be appreciated, a unit cell 400 of the exemplary ELR material includes six "faces": two "a-b" faces that are parallel to the c-plane; two "a-c" faces that are parallel to the b-plane; and two "b-c" faces that are parallel to the a-plane (see, e.g., Figure 13). As would also be appreciated, a "surface" of ELR material in the macro sense may be comprised of multiple unit cells 400 (e.g., hundreds, thousands or more). Reference in this description to a "surface" or "face" of the ELR material being parallel to a particular plane (e.g., the a-plane, the b-plane or the c-plane) indicates that the surface is formed predominately (i.e., a vast majority) of faces of unit cell 400 that are substantially parallel to the particular plane. Furthermore, reference in this description to a "surface" or "face" of the ELR material being parallel to planes other than the a-plane, the b-plane, or the c-plane (e.g., an ab-plane as described below, etc.) indicates that the surface is formed from some mixture of faces of unit cell 400 that, in the aggregate macro sense, form a surface substantially parallel to such other planes.

[0084] Studies indicate that some ELR materials demonstrate an anisotropic (i.e., directional) dependence of the resistance phenomenon. In other words, resistance at a given temperature and current density depends upon a direction in relation to crystalline structure 100. For example, in their ELR state, some ELR materials can carry significantly more current, at extremely low resistance, in the direction of the a-axis and/or in the direction of the b-axis than such materials do in the direction of the c-axis. As would be appreciated, various ELR materials exhibit anisotropy in various performance phenomenon, including the resistance phenomenon, in directions other than, in addition to, or as combinations of those described above. For purposes of this description, reference to a material that tends to exhibit the resistance phenomenon (and similar language) in a first direction indicates that the material supports such phenomenon in the first direction; and reference to a material that tends not to exhibit the

resistance phenomenon (and similar language) in a second direction indicates that the material does not support such phenomenon in the second direction or does so in a reduced manner from other directions.

[0085] With reference to Figure 2, conventional understanding of known ELR materials has thus far failed to appreciate an aperture 210 formed within crystalline structure 100 by a plurality of aperture atoms 250 as being responsible for the resistance phenomenon. (See e.g., Figure 4, where an aperture is not readily apparent in a depiction of single unit cell 400.) In some sense, aperture atoms 250 may be viewed as forming a discrete atomic "boundary" or "perimeter" around aperture 210. In some implementations of the invention and as illustrated in Figure 2, aperture 210 appears between a first portion 220 and a second portion 230 of crystalline structure 100 although in some implementations of the invention, aperture 210 may appear in other portions of various other crystalline structures. Aperture 210 is illustrated in Figure 2 based on depictions of atoms as simple "spheres;" it would be appreciated that such apertures are related to and shaped by, among other things, electrons and their associated electron densities (not otherwise illustrated) of various atoms in crystalline structure 100, including aperture atoms 250.

[0086] According to various aspects of the invention, aperture 210 facilitates propagation of electrical charge through crystalline structure 100 and when aperture 210 facilitates propagation of electrical charge through crystalline structure 100, ELR material operates in its ELR state. For purposes of this description, "propagates," "propagating," and/or "facilitating propagation" (along with their respective forms) generally refer to "conducts," "conducting" and/or "facilitating conduction" and their respective forms; "transports," "transporting" and/or "facilitating transport" and their respective forms; "guides," "guiding" and/or "facilitating guidance" and their respective forms; and/or "carry," "carrying" and/or "facilitating carrying" and their respective forms. For purposes of this description, electrical charge may include positive charge or negative charge, and/or pairs or other groupings of such charges; further, such charge may propagate through crystalline structure 100 in the form of one or more particles or in the form of one or more waves or wave packets.

[0087] In some implementations of the invention, propagation of electrical charge through crystalline structure 100 may be in a manner analogous to that of a waveguide. In some implementations of the invention, aperture 210 may be a waveguide with regard to propagating electrical charge through crystalline structure 100. Waveguides and their operation are generally well understood. In particular, walls surrounding an interior of the

waveguide may correspond to the boundary or perimeter of aperture atoms 250 around aperture 210. One aspect relevant to an operation of a waveguide is its cross-section. At the atomic level, aperture 210 and/or its cross-section may change substantially with changes in temperature of the ELR material. For example, in some implementations of the invention, changes in temperature of the ELR material may cause changes in aperture 210, which in turn may cause the ELR material to transition between its ELR state to its non-ELR state. For example, as temperature of the ELR material increases, aperture 210 may restrict or impede propagation of electrical charge through crystalline structure 100 and the corresponding ELR material may transition from its ELR state to its non-ELR state. Likewise, for example, as temperature of the ELR material decreases, aperture 210 may facilitate (as opposed to restrict or impede) propagation of electrical charge through crystalline structure 100 and the corresponding ELR material may transition from its non-ELR state to its ELR state.

[0088] Apertures, such as aperture 210 in Figure 2, exist in various ELR materials, such as, but not limited to, various ELR materials illustrated in Figure 3 and Figures 5-9, etc., and described below. As illustrated, such apertures are intrinsic to the crystalline structure of some or all the ELR materials. Various forms, shapes, sizes, and numbers of apertures 210 exist in ELR materials depending on the precise configuration of the crystalline structure, composition of atoms, and arrangement of atoms within the crystalline structure of the ELR material as would be appreciated in light of this description.

[0089] The presence and absence of apertures 210 that extend in the direction of various axes through the crystalline structures 100 of various ELR materials is consistent with the anisotropic dependence demonstrated by such ELR materials. For example, ELR material 360, which is illustrated in Figure 3, Figure 11, and Figure 12, corresponds to YBCO-123, which exhibits the resistance phenomenon in the direction of the a-axis and the b-axis, but tends not to exhibit the resistance phenomenon in the direction of the c-axis. Consistent with the anisotropic dependence of the resistance phenomenon demonstrated by YBCO-123, Figure 3 illustrates that apertures 310 extend through crystalline structure 300 in the direction of the a-axis; Figure 12 illustrates that apertures 310 and apertures 1210 extend through crystalline structure 300 in the direction of the b-axis; and Figure 11 illustrates that no suitable apertures extend through crystalline structure 300 in the direction of the c-axis.

[0090] Aperture 210 and/or its cross-section may be dependent upon various atomic characteristics of aperture atoms 250 and/or "non-aperture atoms" (i.e., atoms in crystalline structure 100 other than aperture atoms 250). Such atomic characteristics include, but are not limited to, atomic size, atomic weight, numbers of electrons, electron structure, number of bonds, types of bonds, differing bonds, multiple bonds, bond lengths, bond strengths, bond angles between aperture atoms, bond angles between aperture atoms and non-aperture atoms, and/or isotope number. Aperture atoms 250 and non-aperture atoms may be selected based on their corresponding atomic characteristics to optimize aperture 210 in terms of its size, shape, rigidity, and modes of vibration (in terms of amplitude, frequency, and direction) in relation to crystalline structure and/or atoms therein.

[0091] According to various implementations of the invention, changes in a physical structure of aperture 210, including changes to a shape and/or size of its cross-section and/or changes to the shape or size of aperture atoms 205, may have an impact on the resistance phenomenon. For example, as temperature of crystalline structure 100 increases, the cross-section of aperture 210 may be changed due to vibration of various atoms within crystalline structure 100 as well as changes in energy states, or occupancy thereof, of the atoms in crystalline structure 100. Physical flexure, tension or compression of crystalline structure 100 may also affect the positions of various atoms within crystalline structure 100 and therefore the cross-section of aperture 210. Magnetic fields imposed on crystalline structure 100 may also affect the positions of various atoms within crystalline structure 100 and therefore the cross-section of aperture 210.

[0092] Phonons correspond to various modes of vibration within crystalline structure 100. Phonons in crystalline structure 100 may interact with electrical charge propagated through crystalline structure 100. More particularly, phonons in crystalline structure 100 may cause atoms in crystalline structure 100 (e.g., aperture atoms 250, non-aperture atoms, etc.) to interact with electrical charge propagated through crystalline structure 100. Higher temperatures result in higher phonon amplitude and may result in increased interaction among phonons, atoms in crystalline structure 100, and such electrical charge. Various implementations of the invention may minimize, reduce, or otherwise modify such interaction among phonons, atoms in crystalline structure 100, and such electrical charge within crystalline structure 100.

[0093] Figure 3 illustrates a crystalline structure 300 of an exemplary ELR material 360 from a second perspective. Exemplary ELR material 360 is a superconducting material

commonly referred to as "YBCO" which, in certain formulations, has a transition temperature of approximately 90K. In particular, exemplary ELR material 360 depicted in Figure 3 is YBCO-123. Crystalline structure 300 of exemplary ELR material 360 includes various atoms of yttrium ("Y"), barium ("Ba"), copper ("Cu") and oxygen ("O"). As illustrated in Figure 3, an aperture 310 is formed within crystalline structure 300 by aperture atoms 350, namely atoms of yttrium, copper, and oxygen. A cross-sectional distance between the yttrium aperture atoms in aperture 310 is approximately 0.389 nm, a cross-sectional distance between the oxygen aperture atoms in aperture 310 is approximately 0.285 nm, and a cross-sectional distance between the copper aperture atoms in aperture 310 is approximately 0.339 nm.

[0094] Figure 12 illustrates crystalline structure 300 of exemplary ELR material 360 from a third perspective. Similar to that described above with regard to Figure 3, exemplary ELR material 360 is YBCO-123, and aperture 310 is formed within crystalline structure 300 by aperture atoms 350, namely atoms of yttrium, copper, and oxygen. In this orientation, a cross-sectional distance between the yttrium aperture atoms in aperture 310 is approximately 0.382 nm, a cross-sectional distance between the oxygen aperture atoms in aperture 310 is approximately 0.288 nm, and a cross-sectional distance between the copper aperture atoms in aperture 310 is approximately 0.339 nm. In this orientation, in addition to aperture 310, crystalline structure 300 of exemplary ELR material 360 includes an aperture 1210. Aperture 1210 occurs in the direction of the b-axis of crystalline structure 300. More particularly, aperture 1210 occurs between individual unit cells of exemplary ELR material 360 in crystalline structure 300. Aperture 1210 is formed within crystalline structure 300 by aperture atoms 1250, namely atoms of barium, copper and oxygen. A cross-sectional distance between the barium aperture atoms 1250 in aperture 1210 is approximately 0.430 nm, a cross-sectional distance between the oxygen aperture atoms 1250 in aperture 1210 is approximately 0.382 nm, and a cross-sectional distance between the copper aperture atoms 1250 in aperture 1210 is approximately 0.382 nm. In some implementations of the invention, aperture 1210 operates in a manner similar to that described herein with regard to aperture 310. For purposes of this description, aperture 310 in YBCO may be referred to as an "yttrium aperture," whereas aperture 1210 in YBCO may be referred to as a "barium aperture," based on the compositions of their respective aperture atoms 350, 1250.

[0095] Figure 5 illustrates a crystalline structure 500 of an exemplary ELR material 560 as viewed from the second perspective. Exemplary ELR material 560 is an HTS material

commonly referred to as "HgBa2CuO4" which has a transition temperature of approximately 94K. Crystalline structure 500 of exemplary ELR material 560 includes various atoms of mercury ("Hg"), barium ("Ba"), copper ("Cu"), and oxygen ("O"). As illustrated in Figure 5, an aperture 510 is formed within crystalline structure 500 by aperture atoms which comprise atoms of barium, copper, and oxygen.

[0096] Figure 6 illustrates a crystalline structure 600 of an exemplary ELR material 660 as viewed from the second perspective. Exemplary ELR material 660 is an HTS material commonly referred to as "Tl2Ca2Ba2Cu3O10" which has a transition temperature of approximately 128K. Crystalline structure 600 of exemplary ELR material 660 includes various atoms of thallium ("Tl"), calcium ("Ca"), barium ("Ba"), copper ("Cu"), and oxygen ("O"). As illustrated in Figure 6, an aperture 610 is formed within crystalline structure 600 by aperture atoms which comprise atoms of calcium, barium, copper and oxygen. As also illustrated in Figure 6, a secondary aperture 620 may also be formed within crystalline structure 600 by secondary aperture atoms which comprise atoms of calcium, copper and oxygen. Secondary apertures 620 may operate in a manner similar to that of apertures 610.

[0097] Figure 7 illustrates a crystalline structure 700 of an exemplary ELR material 760 as viewed from the second perspective. Exemplary ELR material 760 is an HTS material commonly referred to as "La2CuO4" which has a transition temperature of approximately 39K. Crystalline structure 700 of exemplary ELR material 760 includes various atoms of lanthanum ("La"), copper ("Cu"), and oxygen ("O"). As illustrated in Figure 7, an aperture 710 is formed within crystalline structure 700 by aperture atoms which comprise atoms of lanthanum and oxygen.

[0098] Figure 8 illustrates a crystalline structure 800 of an exemplary ELR material 860 as viewed from the second perspective. Exemplary ELR material 860 is an HTS material commonly referred to as "As2Ba0.34Fe2K0.66" which has a transition temperature of approximately 38K. Exemplary ELR material 860 is representative of a family of ELR materials sometimes referred to as "iron pnictides." Crystalline structure 800 of exemplary ELR material 860 includes various atoms of arsenic ("As"), barium ("Ba"), iron ("Fe"), and potassium ("K"). As illustrated in Figure 8, an aperture 810 is formed within crystalline structure 800 by aperture atoms which comprise atoms of potassium and arsenic.

[0099] Figure 9 illustrates a crystalline structure 900 of an exemplary ELR material 960 as viewed from the second perspective. Exemplary ELR material 960 is an HTS material

commonly referred to as "MgB2" which has a transition temperature of approximately 39K. Crystalline structure 900 of exemplary ELR material 960 includes various atoms of magnesium ("Mg") and boron ("B"). As illustrated in Figure 9, an aperture 910 is formed within crystalline structure 900 by aperture atoms which comprise atoms of magnesium and boron.

[00100] The foregoing exemplary ELR materials illustrated in Figure 3, Figures 5-9, and Figure 12 each demonstrate the presence of various apertures within such materials. Various other ELR materials have similar apertures. Once attributed to the resistance phenomenon, apertures and their corresponding crystalline structures may be exploited to improve operating characteristics of existing ELR materials, to derive improved ELR materials from existing ELR materials, and/or to design and formulate new ELR materials. For convenience of description, ELR material 360 (and its attendant characteristics and structures) henceforth generally refers to various ELR materials, including, but not limited to, ELR material 560, ELR material 660, ELR material 760, and other ELR materials illustrated in the drawings, not just that ELR material illustrated and described with reference to Figure 3.

[00101] According to various implementations of the invention, the crystalline structure of various known ELR materials may be modified such that the modified ELR material operates with improved operating characteristics over the known and/or unmodified ELR material. In some implementations of the invention, this may also be accomplished, for example, by layering a material over crystalline structure 100 such that atoms of the material span aperture 210 by forming one or more bonds between first portion 220 and second portion 230 as would be appreciated. This particular modification of layering a material over crystalline structure 100 is described in further detail below in connection with various experimental test results.

[00102] Figure 10 illustrates a modified crystalline structure 1010 of a modified ELR material 1060 as viewed from the second perspective in accordance with various implementations of the invention. Figure 11 illustrates modified crystalline structure 1010 of modified ELR material 1060 as viewed from the first perspective in accordance with various implementations of the invention. ELR material 360 (e.g., for example, as illustrated in Figure 3 and elsewhere) is modified to form modified ELR material 1060. Modifying material 1020 forms bonds with atoms of crystalline structure 300 (of Figure 3) of ELR material 360 to form modified crystalline structure 1010 of modified ELR material 1060 as illustrated in Figure 11. As illustrated, modifying material 1020 bridges a gap

between first portion 320 and second portion 330 thereby changing, among other things, vibration characteristics of modified crystalline structure 1010, particularly in the region of aperture 310. In doing so, modifying material 1020 maintains aperture 310 at higher temperatures. Accordingly, in some implementations of the invention, modifying material 1020 is specifically selected to fit in and bond with appropriate atoms in crystalline structure 300.

[00103] In some implementations of the invention and as illustrated in Figure 10, modifying material 1020 is bonded to a face of crystalline structure 300 that is parallel to the b-plane (e.g., an "a-c" face). In such implementations where modifying material 1020 is bonded to the "a-c" face, apertures 310 extending in the direction of the a-axis and with cross-sections lying in the a-plane are maintained. In such implementations, charge carriers flow through aperture 310 in the direction of the a-axis.

[00104] In some implementations of the invention, modifying material 1020 is bonded to a face of crystalline structure 300 that is parallel to the a-plane (e.g., a "b-c" face). In such implementations where modifying material 1020 is bonded to the "b-c" face, apertures 310 extending in the direction of the b-axis and with cross-sections lying in the b-plane are maintained. In such implementations, charge carriers flow through aperture 310 in the direction of the b-axis.

[00105] Various implementations of the invention include layering a particular surface of ELR material 360 with modifying material 1020 (i.e., modifying the particular surface of ELR material 360 with the modifying material 1020). As would be recognized from this description, reference to "modifying a surface" of ELR material 360, ultimately includes modifying a face (and in some cases more that one face) of one or more unit cells 400 of ELR material 360. In other words, modifying material 1020 actually bonds to atoms in unit cell 400 of ELR material 360.

[00106] For example, modifying a surface of ELR material 360 parallel to the a-plane includes modifying "b-c" faces of unit cells 400. Likewise, modifying a surface of ELR material 360 parallel to the b-plane includes modifying "a-c" faces of unit cells 400. In some implementations of the invention, modifying material 1020 is bonded to a surface of ELR material 360 that is substantially parallel to any plane that is parallel to the c-axis. For purposes of this description, planes that are parallel to the c-axis are referred to generally as ab-planes, and as would be appreciated, include the a-plane and the b-plane. As would be appreciated, a surface of ELR material 360 parallel to the ab-plane is formed from some mixture of "a-c" faces and "b-c" faces of unit cells 400. In such

implementations where modifying material 1020 is bonded to a surface parallel to an ab-plane, apertures 310 extending in the direction of the a-axis and apertures 310 extending in the direction of the b-axis are maintained.

[00107] In some implementations of the invention, modifying material 1020 may be a conductive material. In some implementations of the invention, modifying material 1020 may a material with high oxygen affinity (i.e., a material that bonds easily with oxygen) ("oxygen bonding material"). In some implementations of the invention, modifying material 1020 may be a conductive material that bonds easily with oxygen ("oxygen bonding conductive materials"). Such oxygen bonding conductive materials may include, but are not limited to: chromium, copper, bismuth, cobalt, vanadium, and titanium. Such oxygen bonding conductive materials may also include, but are not limited to: rhodium or beryllium. Other modifying materials may include gallium or selenium. Other modifying materials may include silver. Still other modifying materials may be used.

[00108] In some implementations of the invention, oxides of modifying material 1020 may form during various operations associated with modifying ELR material 360 with modifying material 1020. Accordingly, in some implementations of the invention, modifying material 1020 may include a substantially pure form of modifying material 1020 and/or various oxides of modifying material 1020. In other words, in some implementations of the invention, ELR material 360 is modified with modifying material 1020 and/or various oxides of modifying material 1020. By way of example, but not limitation, in some implementations of the invention, modifying material 1020 may comprise chromium and/or chromium oxide (CrxOy).

[00109] In some implementations of the invention, ELR material 360 may be YBCO and modifying material 1020 may be an oxygen bonding conductive material. In some implementations of the invention, ELR material 360 may be YBCO and modifying material 1020 may be selected from the group including, but not limited to: chromium, copper, bismuth, cobalt, vanadium, titanium, rhodium, or beryllium. In some implementations of the invention, ELR material 360 may be YBCO and modifying material 1020 may be selected from the group consisting of: chromium, copper, bismuth, cobalt, vanadium, titanium, rhodium, and beryllium. In some implementations of the invention, ELR material 360 may be YBCO and modifying material 1020 may be another modifying material.

[00110] In some implementations of the invention, various other combinations of mixed-valence copper-oxide perovskite materials and oxygen bonding conductive

materials may be used. For example, in some implementations of the invention, ELR material 360 corresponds to a mixed-valence copper-oxide perovskite material commonly referred to as "BSCCO." BSCCO includes various atoms of bismuth ("Bi"), strontium ("Sr"), calcium ("Ca"), copper ("Cu") and oxygen ("O"). By itself, BSCCO has a transition temperature of approximately 100K. In some implementations of the invention, ELR material 360 may be BSCCO and modifying material 1020 may be an oxygen bonding conductive material. In some implementations of the invention, ELR material 360 may be BSCCO and modifying material 1020 may be selected from the group including, but not limited to: chromium, copper, bismuth, cobalt, vanadium, titanium, rhodium, or beryllium. In some implementations of the invention, ELR material 360 may be BSCCO and modifying material 1020 may be selected from the group consisting of: chromium, copper, bismuth, cobalt, vanadium, titanium, rhodium, and beryllium. In some implementations of the invention, ELR material 360 may be BSCCO and modifying material 1020 may be another modifying material.

[00111] In some implementations of the invention, various combinations of other ELR materials and modifying materials may be used. For example, in some implementations of the invention, ELR material 360 corresponds to an iron pnictide material. Iron pnictides, by themselves, have transition temperatures that range from approximately 25-60K. In some implementations of the invention, ELR material 360 may be an iron pnictide and modifying material 1020 may be an oxygen bonding conductive material. In some implementations of the invention, ELR material 360 may be an iron pnictide and modifying material 1020 may be selected from the group including, but not limited to: chromium, copper, bismuth, cobalt, vanadium, titanium, rhodium, or beryllium. In some implementations of the invention, ELR material 360 may be an iron pnictide and modifying material 1020 may be selected from the group consisting of: chromium, copper, bismuth, cobalt, vanadium, titanium, rhodium, and beryllium. In some implementations of the invention, ELR material 360 may be an iron pnictide and modifying material 1020 may be another modifying material.

[00112] In some implementations of the invention, various combinations of other ELR materials and modifying materials may be used. For example, in some implementations of the invention, ELR material 360 may be magnesium diboride ("MgB2"). By itself, magnesium diboride has a transition temperature of approximately 39K. In some implementations of the invention, ELR material 360 may be magnesium diboride and modifying material 1020 may be an oxygen bonding conductive material. In some

implementations of the invention, ELR material 360 may be magnesium diboride and modifying material 1020 may be selected from the group including, but not limited to: chromium, copper, bismuth, cobalt, vanadium, titanium, rhodium, or beryllium. In some implementations of the invention, ELR material 360 may be magnesium diboride and modifying material 1020 may be selected from the group consisting of: chromium, copper, bismuth, cobalt, vanadium, titanium, rhodium, and beryllium. In some implementations of the invention, ELR material 360 may be magnesium diboride and modifying material 1020 may be another modifying material.

[00113] In some implementations of the invention, modifying material 1020 may be layered onto a sample of ELR material 360 using various techniques for layering one composition onto another composition as would be appreciated. For example, such layering techniques include, but are not limited to, pulsed laser deposition, evaporation including coevaporation, e-beam evaporation and activated reactive evaporation, sputtering including magnetron sputtering, ion beam sputtering and ion assisted sputtering, cathodic arc deposition, CVD, organometallic CVD, plasma enhanced CVD, molecular beam epitaxy, a sol-gel process, liquid phase epitaxy and/or other layering techniques. In some implementations of the invention, ELR material 360 may be layered onto a sample of modifying material 1020 using various techniques for layering one composition onto another composition. In some implementations of the invention, a single atomic layer of modifying material 1020 (i.e., a layer of modifying material 1020 having a thickness substantially equal to a single atom or molecule of modifying material 1020) may be layered onto a sample of ELR material 360. In some implementations of the invention, a single unit layer of the modifying material (i.e., a layer of the modifying material having a thickness substantially equal to a single unit (e.g., atom, molecule, crystal, or other unit) of the modifying material) may be layered onto a sample of the ELR material. In some implementations of the invention, the ELR material may be layered onto a single unit layer of the modifying material. In some implementations of the invention, two or more unit layers of the modifying material may be layered onto the ELR material. In some implementations of the invention, the ELR material may be layered onto two or more unit layers of the modifying material.

[00114] In some implementations of the invention, modifying ELR material 360 with modifying material 1020 maintains aperture 310 within modified ELR material 1060 at temperatures at, about, or above that of the boiling point of nitrogen. In some implementations of the invention, aperture 310 is maintained at temperatures at, about,

or above that the boiling point of carbon dioxide. In some implementations of the invention, aperture 310 is maintained at temperatures at, about, or above that of the boiling point of ammonia. In some implementations of the invention, aperture 310 is maintained at temperatures at, about, or above that of the boiling point of various formulations of Freon. In some implementations of the invention, aperture 310 is maintained at temperatures at, about, or above that of the melting point of water. In some implementations of the invention, aperture 310 is maintained at temperatures at, about, or above that of the melting point of a solution of water and antifreeze. In some implementations of the invention, aperture 310 is maintained at temperatures at, about, or above that of room temperature (e.g., 21oC). In some implementations of the invention, aperture 310 is maintained at temperatures at, about, or above a temperature selected from one of the following set of temperatures: 150K, 160K, 170K, 180K, 190K, 200K, 210K, 220K, 230K, 240K, 250K, 260K, 270K, 280K, 290K, 300K, 310K. In some implementations of the invention, aperture 310 is maintained at temperatures within the range of 150K to 315K.

[00115] Figures 14A-14G illustrate test results 1400 obtained as described above. Test results 1400 include a plot of resistance of modified ELR material 1060 as a function of temperature (in K). More particularly, test results 1400 correspond to modified ELR material 1060 where modifying material 1020 corresponds to chromium and where ELR material 360 corresponds to YBCO. Figure 14A includes test results 1400 over a full range of temperature over which resistance of modified ELR material 1060 was measured, namely 84K to 286K. In order to provide further detail, test results 1400 were broken into various temperature ranges and illustrated. In particular, Figure 14B illustrates those test results 1400 within a temperature range from 240K to 280K; Figure 14C illustrates those test results 1400 within a temperature range from 210K to 250K; Figure 14D illustrates those test results 1400 within a temperature range from 180K to 220K; Figure 14E illustrates those test results 1400 within a temperature range from 150K to 190K; Figure 14F illustrates those test results 1400 within a temperature range from 120K to 160K; and Figure 14G illustrates those test results 1400 within a temperature range from 84.5K to 124.5K.

[00116] Test results 1400 demonstrate that various portions of modified ELR material 1060 operate in an ELR state at higher temperatures relative to ELR material 360. Six sample analysis test runs were made. For each sample analysis test run, modified ELR material 1060 was slowly cooled from approximately 286K to 83K. While being cooled,

the current source applied +60 nA and -60 nA of current in a delta mode configuration in order to reduce impact of any DC offsets and/or thermocouple effects. At regular time intervals, the voltage across modified ELR material 1060 was measured by the voltmeter. For each sample analysis test run, the time series of voltage measurements were filtered using a 512-point fast Fourier transform ("FFT"). All but the lowest 44 frequencies from the FFT were eliminated from the data and the filtered data was returned to the time domain. The filtered data from each sample analysis test run were then merged together to produce test results 1400. More particularly, all the resistance measurements from the six sample analysis test runs were organized into a series of temperature ranges (e.g., 80K-80.25K, 80.25K to 80.50, 80.5K to 80.75K, etc.) in a manner referred to as "binning." Then the resistance measurements in each temperature range were averaged together to provide an average resistance measurement for each temperature range. These average resistance measurements form test results 1400.

[00117] Test results 1400 include various discrete steps 1410 in the resistance versus temperature plot, each of such discrete steps 1410 representing a relatively rapid change in resistance over a relatively narrow range of temperatures. At each of these discrete steps 1410, discrete portions of modified ELR material 1060 begin propagating electrical charge up to such portions' charge propagating capacity at the respective temperatures. At very small scales, the surface of ELR material 360 being modified is not perfectly smooth, and thus apertures 310 exposed within the surface of ELR material 360 typically do not extend across the entire width or length of the sample of modified ELR material 1060. Accordingly, in some implementations of the invention, modifying material 1020 covers an entire surface of ELR material 360 and may act as a conductor that carries electrical charge between apertures 310.

[00118] Before discussing test results 1400 in further detail, various characteristics of ELR material 360 and modifying material 1020 are discussed. Resistance versus temperature ("R-T") profiles of these materials individually are generally well known. The individual R-T profiles of these materials are not believed to include features similar to discrete steps 1410 found in test results 1400. In fact, unmodified samples of ELR material 360 and samples of modifying material 1020 alone have been tested under similar and often identical testing and measurement configurations. In each instance, the R-T profile of the unmodified samples of ELR material 360 and the R-T profile of the modifying material alone did not include any features similar to discrete steps 1410. Accordingly, discrete steps 1410 are the result of modifying ELR material 360 with

modifying material 1020 to maintain aperture 310 at increased temperatures thereby allowing modified material 1060 to remain in an ELR state at such increased temperatures in accordance with various implementations of the invention.

[00119] At each of discrete steps 1410, various ones of apertures 310 within modified ELR material 1060 start propagating electrical charge up to each aperture's 310 charge propagating capacity. As measured by the voltmeter, each charge propagating aperture 310 appears as a short-circuit, dropping the apparent voltage across the sample of modified ELR material 1060 by a small amount. The apparent voltage continues to drop as additional ones of apertures 310 start propagating electrical charge until the temperature of the sample of modified ELR material 1060 reaches the transition temperature of ELR material 360 (i.e., the transition temperature of the unmodified ELR material which in the case of YBCO is approximately 90K).

[00120] Test results 1400 indicate that certain apertures 310 within modified ELR material 1060 propagate electrical charge at approximately 97K, 100K, 103K, 113K, 126K, 140K, 146K, 179K, 183.5K, 200.5K, 237.5K, and 250K. Certain apertures 310 within modified ELR material 1060 may propagate electrical charge at other temperatures within the full temperature range as would be appreciated.

[00121] Test results 1400 include various other relatively rapid changes in resistance over a relatively narrow range of temperatures not otherwise identified as a discrete step 1410. Some of these other changes may correspond to artifacts from data processing techniques used on the measurements obtained during the test runs (e.g., FFTs, filtering, etc.). Some of these other changes may correspond to changes in resistance due to resonant frequencies in modified crystalline structure 1010 affecting aperture 310 at various temperatures. Some of these other changes may correspond to additional discrete steps 1410. In addition, changes in resistance in the temperature range of 270-274K are likely to be associated with water present in modified ELR material 1060, some of which may have been introduced during preparation of the sample of modified ELR material 1060.

[00122] In addition to discrete steps 1410, test results 1400 differ from the R-T profile of ELR material 360 in that modifying material 1020 conducts well at temperatures above the transition temperature of ELR material 360 whereas ELR material 360 typically does not.

[00123] Figure 15 illustrates additional test results 1500 for samples of ELR material 360 and modifying material 1020. More particularly, for test results 1500, modifying material

1020 corresponds to chromium and ELR material 360 corresponds to YBCO. For test results 1500, samples of ELR material 360 were prepared, using various techniques discussed above, to expose a face of crystalline structure 300 parallel to the a-plane or the b-plane. Test results 1500 were gathered using a lock-in amplifier and a K6221 current source, which applied a 10nA current at 24.0, Hz to modified ELR material 1060. Test results 1500 include a plot of resistance of modified ELR material 1060 as a function of temperature (in K). Figure 15 includes test results 1500 over a full range of temperature over which resistance of modified ELR material 1060 was measured, namely 80K to 275K. Test results 1500 demonstrate that various portions of modified ELR material 1060 operate in an ELR state at higher temperatures relative to ELR material 360. Five sample analysis test runs were made with a sample of modified ELR material 1060. For each sample analysis test run, the sample of modified ELR material 1060 was slowly warmed from 80K to 275K. While being warmed, the voltage across the sample of modified ELR material 1060 was measured at regular time intervals and the resistance was calculated based on the source current. For each sample analysis test run, the time series of resistance measurements were filtered using a 1024-point FFT. All but the lowest 15 frequencies from the FFT were eliminated from the data and the filtered resistance measurements were returned to the time domain. The filtered resistance measurements from each sample analysis test run were then merged together using the binning process referred to above to produce test results 1500. Then the resistance measurements in each temperature range were averaged together to provide an average resistance measurement for each temperature range. These average resistance measurements form test results 1500.

[00124] Test results 1500 include various discrete steps 1510 in the resistance versus temperature plot, each of such discrete steps 1510 representing a relatively rapid change in resistance over a relatively narrow range of temperatures, similar to discrete steps 1410 discussed above with respect to Figures 14A-14G. At each of these discrete steps 1510, discrete portions of modified ELR material 1060 propagate electrical charge up to such portions' charge propagating capacity at the respective temperatures.

[00125] Test results 1500 indicate that certain apertures 310 within modified ELR material 1060 propagate electrical charge at approximately 120K, 145K, 175K, 225K, and 250K. Certain apertures 310 within modified ELR material 1060 may propagate electrical charge at other temperatures within the full temperature range as would be appreciated.

[00126] Figures 16-20 illustrate additional test results for samples of ELR material 360 and various modifying materials 1020. For these additional test results, samples of ELR material 360 were prepared, using various techniques discussed above, to expose a face of crystalline structure 300 substantially parallel to the a-plane or the b-plane or some combination of the a-plane or the b-plane and the modifying material was layered onto these exposed faces. Each of these modified samples was slowly cooled from approximately 300K to 80K. While being warmed, a current source applied a current in a delta mode configuration through the modified sample as described below. At regular time intervals, the voltage across the modified sample was measured. For each sample analysis test run, the time series of voltage measurements were filtered in the frequency domain using an FFT by removing all but the lowest frequencies, and the filtered measurements were returned to the time domain. The number of frequencies kept is in general different for each data set. The filtered data from each of test runs were then binned and averaged together to produce the test results illustrated in Figures 16-21.

[00127] Figure 16 illustrates test results 1600 including a plot of resistance of modified ELR material 1060 as a function of temperature (in K). For test results 1600, modifying material 1020 corresponds to vanadium and ELR material 360 corresponds to YBCO. Test results 1600 were produced over 11 test runs using a 20nA current source, a 1024-point FFT was performed, and information from all but the lowest 12 frequencies were eliminated. Test results 1600 demonstrate that various portions of modified ELR material 1060 operate in an ELR state at higher temperatures relative to ELR material 360. Test results 1600 include various discrete steps 1610 in the resistance versus temperature plot, similar to those discussed above with regard to Figures 14A-14G. Test results 1600 indicate that certain apertures 310 within modified ELR material 1060 propagate electrical charge at approximately 267K, 257K, 243K, 232K, and 219K. Certain apertures 310 within modified ELR material 1060 may propagate electrical charge at other temperatures.

[00128] Figure 17 illustrates test results 1700 including a plot of resistance of modified ELR material 1060 as a function of temperature (in K). For test results 1700, modifying material 1020 corresponds to bismuth and ELR material 360 corresponds to YBCO. Test results 1700 were produced over 5 test runs using a 400nA current source, a 1024-point FFT was performed, and information from all but the lowest 12 frequencies were eliminated. Test results 1700 demonstrate that various portions of modified ELR material 1060 operate in an ELR state at higher temperatures relative to ELR material 360. Test

results 1700 include various discrete steps 1710 in the resistance versus temperature plot, similar to those discussed above with regard to Figures 14A-14G. Test results 1700 indicate that certain apertures 310 within modified ELR material 1060 propagate electrical charge at approximately 262K, 235K, 200K, 172K, and 141K. Certain apertures 310 within modified ELR material 1060 may propagate electrical charge at other temperatures.

[00129] Figure 18 illustrates test results 1800 including a plot of resistance of modified ELR material 1060 as a function of temperature (in K). For test results 1800, modifying material 1020 corresponds to copper and ELR material 360 corresponds to YBCO. Test results 1800 were produced over 6 test runs using a 200nA current source, a 1024-point FFT was performed, and information from all but the lowest 12 frequencies were eliminated. Test results 1800 demonstrate that various portions of modified ELR material 1060 operate in an ELR state at higher temperatures relative to ELR material 360. Test results 1800 include various discrete steps 1810 in the resistance versus temperature plot, similar to those discussed above with regard to Figures 14A-14G. Test results 1800 indicate that certain apertures 310 within modified ELR material 1060 propagate electrical charge at approximately 268K, 256K, 247K, 235K, and 223K. Certain apertures 310 within modified ELR material 1060 may propagate electrical charge at other temperatures.

[00130] Figure 19 illustrates test results 1900 including a plot of resistance of modified ELR material 1060 as a function of temperature (in K). For test results 1900, modifying material 1020 corresponds to cobalt and ELR material 360 corresponds to YBCO. Test results 1900 were produced over 11 test runs using a 400nA current source, a 1024-point FFT was performed, and information from all but the lowest 12 frequencies were eliminated. Test results 1900 demonstrate that various portions of modified ELR material 1060 operate in an ELR state at higher temperatures relative to ELR material 360. Test results 1900 include various discrete steps 1910 in the resistance versus temperature plot, similar to those discussed above with regard to Figures 14A-14G. Test results 1900 indicate that certain apertures 310 within modified ELR material 1060 propagate electrical charge at approximately 265K, 236K, 205K, 174K, and 143K. Certain apertures 310 within modified ELR material 1060 may propagate electrical charge at other temperatures.

[00131] Figure 20 illustrates test results 2000 including a plot of resistance of modified ELR material 1060 as a function of temperature (in K). For test results 2000, modifying

material 1020 corresponds to titanium and ELR material 360 corresponds to YBCO. Test results 2000 were produced over 25 test runs using a 100nA current source, a 512-point FFT was performed, and information from all but the lowest 11 frequencies were eliminated. Test results 2000 demonstrate that various portions of modified ELR material 1060 operate in an ELR state at higher temperatures relative to ELR material 360. Test results 2000 include various discrete steps 2010 in the resistance versus temperature plot, similar to those discussed above with regard to Figures 14A-14G. Test results 2000 indicate that certain apertures 310 within modified ELR material 1060 propagate electrical charge at approximately 266K, 242K, and 217K. Certain apertures 310 within modified ELR material 1060 may propagate electrical charge at other temperatures.

[00132] Figure 21A-21B illustrates test results 2100 including a plot of resistance of modified ELR material 1060 as a function of temperature (in K). For test results 2100, modifying material 1020 corresponds to chromium and ELR material 360 corresponds to BSSCO. Figure 21A includes test results 2100 over a full range of temperature over which resistance of modified ELR material 1060 was measured, namely 80K to 270K. In order to provide further detail, test results 2100 were expanded over a temperature range of 150K-250K as illustrated in Figure 21B. Test results 2100 were gathered in a manner similar to those discussed above with regard to FIG. 16-20. In particular, test results 2100 were produced over 25 test runs using a 300nA current source. The data from these test runs was Savitzy-Golay smoothed, using 64 side points and 4th order polynomials. Test results 2100 demonstrate that various portions of modified ELR material 1060 operate in an ELR state at higher temperatures relative to ELR material 360 (here, BSSCO). Test results 2100 include various discrete steps 2110 in the resistance versus temperature plot, similar to those discussed above with regard to Figures 14A-14G. Test results 2100 indicate that certain apertures within modified ELR material 1060 propagate electrical charge at approximately 184K and 214K. Certain apertures 310 within modified ELR material 1060 may propagate electrical charge at other temperatures.

[00133] In other experiments, modifying material 1020 was layered onto a surface of ELR material 360 substantially parallel to the c-plane of crystalline structure 300. These tests results (not otherwise illustrated) demonstrate that layering a surface of ELR material 360 parallel to the c-plane with modifying material 1020 did not produce any discrete steps such as those described above (e.g., discrete steps 1410). These test results indicate that modifying a surface of ELR material 360 that is perpendicular to a

direction in which ELR material 360 does not (or tends to not) exhibit the resistance phenomenon does not improve the operating characteristics of the unmodified ELR material. In other words, modifying such surfaces of ELR material 360 may not maintain aperture 310. In accordance with various principles of the invention, modifying material should be layered with surfaces of the ELR material that are parallel to the direction in which ELR material does not (or tends to not) exhibit the resistance phenomenon. More particularly, and for example, with regard to ELR material 360 (illustrated in Figure 3), modifying material 1020 should be bonded to an "a-c" face or a "b-c" face of crystalline structure 300 (both of which faces are parallel to the c-axis) in ELR material 360 (which tends not to exhibit the resistance phenomenon in the direction of the c-axis) in order to maintain aperture 310.

[00134] Figure 22 illustrates an arrangement 2200 including alternating layers of ELR material 360 and a modifying material 1020 useful for propagating additional electrical charge according to various implementations of the invention. Such layers may be deposited onto one another using various deposition techniques. Various techniques may be used to improve alignment of crystalline structures 300 within layers of ELR material 360. Improved alignment of crystalline structures 300 may result in apertures 310 of increased length through crystalline structure 300 which in turn may provide for operation at higher temperatures and/or with increased charge propagating capacity. Arrangement 2200 provides increased numbers of apertures 310 within modified ELR material 1060 at each interface between adjacent layers of modifying material 1020 and ELR material 360. Increased numbers of apertures 310 may increase a charge propagating capacity of arrangement 2200.

[00135] In some implementations of the invention, any number of layers may be used. In some implementations of the invention, other ELR materials and/or other modifying materials may be used. In some implementations of the invention, additional layers of other material (e.g., insulators, conductors, or other materials) may be used between paired layers of ELR material 360 and modifying material 1020 to mitigate various effects (e.g., magnetic effects, migration of materials, or other effects) or to enhance the characteristics of the modified ELR material 1060 formed within such paired layers. In some implementations of the invention, not all layers are paired. In other words, arrangement 2200 may have one or more extra (i.e., unpaired) layers of ELR material 360 or one or more extra layers of modifying material 1020.

[00136] Figure 23 illustrates additional layers 2310 (illustrated as a layer 2310A, a layer 2310B, a layer 2310C, and a layer 2310D) of modified crystalline structure 1010 in modified ELR material 1060 according to various implementations of the invention. As illustrated, modified ELR material 1060 includes various apertures 310 (illustrated as an aperture 310A, an aperture 310B, and an aperture 310C) at different distances into material 1060 from modifying material 1020 that form bonds with atoms of crystalline structure 300 (of Figure 3). Aperture 310A is nearest modifying material 1020, followed by aperture 310B, which in turn is followed by aperture 310C, etc. In accordance with various implementations of the invention, an impact of modifying material 1020 is greatest with respect to aperture 310A, followed by a lesser impact with respect to aperture 310B, which in turn is followed by a lesser impact with respect to aperture 310C, etc. According to some implementations of the invention, modifying material 1020 should better maintain aperture 310A than either aperture 310B or aperture 310C due to aperture 310A's proximity to modifying material 1020; likewise, modifying material 1020 should better maintain aperture 310B than aperture 310C due to aperture 310B's proximity to modifying material 1020, etc. According to some implementations of the invention, modifying material 1020 should better maintain the cross-section of aperture 310A than the cross-sections of either aperture 310B or aperture 310C due to aperture 310A's proximity to modifying material 1020; likewise, modifying material 1020 should better maintain the cross-section of aperture 310B than the cross-section of aperture 310C due to aperture 310B's proximity to modifying material 1020, etc. According to some implementations of the invention, modifying material 1020 should have a greater impact on a charge propagating capacity of aperture 310A at a particular temperature than on a charge propagating capacity of either aperture 310B or aperture 310C at that particular temperature due to aperture 310A's proximity to modifying material 1020; likewise, modifying material 1020 should have a greater impact on the charge propagating capacity of aperture 310B at a particular temperature than on the charge propagating capacity of aperture 310C at that particular temperature due to aperture 310B's proximity to modifying material 1020, etc. According to some implementations of the invention, modifying material 1020 should enhance the propagation of electrical charge through aperture 310A more than the propagation of electrical charge through either aperture 310B or aperture 310C due to aperture 310A's proximity to modifying material 1020; likewise, modifying material 1020 should enhance the propagation of

electrical charge through aperture 310B more than the propagation of electrical charge through aperture 310C due to aperture 310B's proximity to modifying material 1020, etc.

[00137] Various test results described above, for example, test results 1400 of Figure 14, among others, support these aspects of various implementations of the invention, i.e., generally, that the impact of modifying material 1020 on apertures 310 varies in relation to their proximity to one another. In particular, each discrete step 1410 in test results 1400 may correspond to a change in electrical charge carried by modified ELR material 1060 as those apertures 310 in a particular layer 2310 (or more appropriately, those apertures 310 formed between adjacent layers 2310 as illustrated) propagate electrical charge up to such apertures' 310 charge propagating capacity. Those apertures 310 in layers 2310 closer in proximity to modifying material 1020 correspond to discrete steps 1410 at higher temperatures whereas those apertures 310 in layers 2310 further from modifying material 1020 correspond to discrete steps 1410 at lower temperatures. Discrete steps 1410 are "discrete" in the sense that apertures 310 at a given relative distance to modifying material 1020 (i.e., apertures 310A between layers 2310A and 2310B) propagate electrical charge at a particular temperature and quickly reach their maximum charge propagating capacity. Another discrete step 1410 is reached when apertures 310 at an increased distance from modifying material 1020 (i.e., apertures 310B between layers 2310B and 2310C) propagate electrical charge at a lower temperature as a result of the increased distance and hence the lessened impact of modifying material 1020 on those apertures 310. Each discrete step 1410 corresponds to another set of apertures 310 beginning to carry electrical charge based on their distance from modifying material 1020. At some distance, however, modifying material 1020 may have insufficient impact on some apertures 310 to cause them to carry electrical charge at a higher temperature than they otherwise would; hence, such apertures 310 propagate electrical charge at a temperature consistent with that of ELR material 360.

[00138] In some implementations of the invention, a distance between modifying material 1020 and apertures 310 is reduced so as to increase impact of modifying material 1020 on more apertures 310. In effect, more apertures 310 should propagate electrical charge at discrete steps 1410 associated with higher temperatures. For example, in arrangement 2200 of Figure 22 and in accordance with various implementations of the invention, layers of ELR material 360 may be made to be only a few unit cells thick in order to reduce the distance between apertures 310 in ELR

material 360 and modifying material 1020. Reducing this distance should increase the number of apertures 310 impacted by modifying material 1020 at a given temperature. Reducing this distance also increases the number of alternating layers of ELR material 360 in a given overall thickness of arrangement 2200 thereby increasing an overall charge propagating capacity of arrangement 2200.

[00139] Figure 24 illustrates a film 2400 of an ELR material 2410 formed on a substrate 2420, although, substrate 2420 may not be necessary in various implementations of the invention. In various implementations of the invention, film 2400 may be formed into a tape having a length, for example, greater than 10 cm, 1 m, 1 km or more. Such tapes may be useful, for example, as ELR conductors or ELR wires. As would be appreciated, while various implementations of the invention are described in reference to ELR films, such implementations apply to ELR tapes as well.

[00140] For purposes of this description and as illustrated in Figure 24, film 2400 has a primary surface 2430 and a principal axis 2440. Principal axis 2440 corresponds to a axis extending along a length of film 2400 (as opposed to a width of film 2400 or a thickness of film 2400). Principal axis 2440 corresponds to a primary direction in which electrical charge flows through film 2400. Primary surface 2430 corresponds to the predominant surface of film 2400 as illustrated in Figure 24, and corresponds to the surface bound by the width and the length of film 2400. It should be appreciated that films 2400 may have various lengths, widths, and/or thicknesses without departing from the scope of the invention.

[00141] In some implementations of the invention, during the fabrication of film 2400, the crystalline structures of ELR material 2410 may be oriented such that their c-axis is substantially perpendicular to primary surface 2430 of film 2400 and either the a-axis or the b-axis of their respective crystalline structures is substantially parallel to principal axis 2440. Hence, as illustrated in Figure 24, the c-axis is referenced by name and the a-axis and the b-axis are not specifically labeled, reflecting their interchangeability for purposes of describing various implementations of the invention. In some fabrication processes of film 2400, the crystalline structures of ELR material may be oriented such that any given line within the c-plane may be substantially parallel with principal axis 2440.

[00142] For purposes of this description, films 2400 having the c-axis of their respective crystalline structures oriented substantially perpendicular to primary surface 2430 (including film 2400 depicted in Figure 24) are referred to as “c-films” (i.e., c-film 2400).

C-film 2400, with ELR material 2410 comprised of YBCO, is commercially available from, for example, American SuperconductorsTM (e.g., 344 Superconductor – Type 348C) or Theva Dünnschichttechnik GmbH (e.g., HTS coated conductors).

[00143] In some implementations of the invention, substrate 2420 may include a substrate material including, but not limited to, MgO, STO, LSGO, a polycrystalline material such as a metal or a ceramic, an inert oxide material, a cubic oxide material, a rare earth oxide material, or other substrate material as would be appreciated.

[00144] According to various implementations of the invention (and as described in further detail below), a modifying material 1020 is layered onto an appropriate surface of ELR material 2410, where the appropriate surface of ELR material 2410 corresponds to any surface not substantially perpendicular to the c-axis of the crystalline structure of ELR material 2410. In other words, the appropriate surface of ELR material 2410 may correspond to any surface that is not substantially parallel to the primary surface 2430. In some implementations of the invention, the appropriate surface of ELR material 2410 may correspond to any surface that is substantially parallel to the c-axis of the crystalline structure of ELR material 2410. In some implementations of the invention, the appropriate surface of ELR material 2410 may correspond to any surface that is not substantially perpendicular to the c-axis of the crystalline structure of ELR material 2410. In order to modify an appropriate surface of c-film 2400 (whose primary surface 2430 is substantially perpendicular to the c-axis of the crystalline structure of ELR material 2410), the appropriate surface of ELR material 2410 may be formed on or within c-film 2400. In some implementations of the invention, primary surface 2430 may be processed to expose appropriate surface(s) of ELR material 2410 on or within c-film 2400 on which to layer modifying material. In some implementations of the invention, primary surface 2430 may be processed to expose one or more apertures 210 of ELR material 2410 on or within c-film 2400 on which to layer modifying material. It should be appreciated, that in various implementations of the invention, modifying material may be layered onto primary surface 2430 in addition to the appropriate surfaces referenced above.

[00145] Processing of primary surface 2430 of c-film 2400 to expose appropriate surfaces and/or apertures 210 of ELR material 2410 may comprise various patterning techniques, including various wet processes or dry processes. Various wet processes may include lift-off, chemical etching, or other processes, any of which may involve the use of chemicals and which may expose various other surfaces within c-film 2400. Various dry processes may include ion or electron bream irradiation, laser direct-writing,

laser ablation or laser reactive patterning or other processes which may expose various appropriate surfaces and/or apertures 210 of ELR material 2410 within c-film 2400.

[00146] As illustrated in Figure 25, primary surface 2430 of c-film 2400 may be processed to expose an appropriate surface within c-film 2400. For example, c-film 2400 may be processed to expose a face within c-film 2400 substantially parallel to the b-plane of crystalline structure 100 or a face within c-film 2400 substantially parallel to the a-plane of crystalline structure 100. More generally, in some implementations of the invention, primary surface 2430 of c-film 2400 may be processed to expose an appropriate surface within c-film 2400 corresponding to an a/b-c face (i.e., a face substantially parallel to ab-plane). In some implementations of the invention, primary surface 2430 of c-film may be processed to expose any face within c-film 2400 that is not substantially parallel with primary surface 2430. In some implementations of the invention, primary surface 2430 of c-film may be processed to expose any face within c-film 2400 that is not substantially parallel with primary surface 2430 and also substantially parallel with principal axis 2440. Any of these faces, including combinations of these faces, may correspond to appropriate surfaces of ELR material 2410 on or within c-film 2400. According to various implementations of the invention, appropriate surfaces of ELR material 2410 provide access to or otherwise "expose" apertures 210 in ELR material 2410 for purposes of maintaining such apertures 210.

[00147] In some implementations of the invention, as illustrated in Figure 25, primary surface 2430 is processed to form one or more grooves 2510 in primary surface 2430. Grooves 2510 include one or more appropriate surfaces (i.e., surfaces other than one substantially parallel to primary surface 2430) on which to deposit modifying material. While grooves 2510 are illustrated in Figure 25 as having a cross section substantially rectangular in shape, other shapes of cross sections may be used as would be appreciated. In some implementations of the invention, the width of grooves 2510 may be greater than 10nm. In some implementations of the invention and as illustrated in Figure 25, the depth of grooves 2510 may be less than a full thickness of ELR material 2410 of c-film 2400. In some implementations of the invention and as illustrated in Figure 26, the depth of grooves 2510 may be substantially equal to the thickness of ELR material 2410 of c-film 2400. In some implementations of the invention, the depth of grooves 2510 may extend through ELR material 2410 of c-film 2400 and into substrate 2420 (not otherwise illustrated). In some implementations of the invention, the depth of grooves 2510 may correspond to a thickness of one or more units of ELR material 2410

(not otherwise illustrated). Grooves 2510 may be formed in primary surface 2430 using various techniques, such as, but not limited to, laser etching, or other techniques.

[00148] In some implementations of the invention, the length of grooves 2510 may correspond to the full length of c-film 2400. In some implementations of the inventions, grooves 2510 are substantially parallel to one another and to principal axis 2440. In some implementations of the invention, grooves 2510 may take on various configurations and/or arrangements in accordance with the various aspects of the invention. For example, grooves 2510 may extend in any manner and/or direction and may include lines, curves and/or other geometric shapes in cross-section with varying sizes and/or shapes along its extent.

[00149] While various aspects of the invention are described as forming grooves 2510 within primary surface 2430, it will be appreciated that bumps, angles, or protrusions that include appropriate surfaces of ELR material 2410 may be formed on substrate 2420 to accomplish similar geometries.

[00150] According to various implementations of the invention, c-film 2400 may be modified to form various modified c-films. For example, referring to Figure 27, a modifying material 2720 (i.e., modifying material 1020, modifying material 1020) may be layered onto primary surface 2430 and into grooves 2510 formed within primary surface 2430 of an unmodified c-film (e.g., c-film 2400) and therefore onto various appropriate surfaces 2710 to form a modified c-film 2700. Appropriate surfaces 2710 may include any appropriate surfaces discussed above. While appropriate surfaces 2710 are illustrated in Figure 27 as being perpendicular to primary surface 2430, this is not necessary as would be appreciated from this description.

[00151] In some implementations of the invention, modifying material 2720 may be layered onto primary surface 2430 and into grooves 2510 as illustrated in Figure 27. In some implementations, such as illustrated in Figure 28, modifying material 2720 may be removed from primary surface 2430 to form modified c-film 2800 using various techniques such that modifying material 2720 remains only in grooves 2510 (e.g., various polishing techniques). In some implementations, modified c-film 2800 may be accomplished by layering modifying material 2720 only in grooves 2510. In other words, in some implementations, modifying material 2720 may be layered only into grooves 2510 and/or onto appropriate surfaces 2710, without layering modifying material 2720 onto primary surface 2430 or may be layered such that modifying material 2720 does not bond or otherwise adhere to primary surface 2430 (e.g., using various masking

techniques). In some implementations of the invention, various selective deposition techniques may be employed to layer modifying material 2720 directly onto appropriate surfaces 2710.

[00152] The thickness of modifying material 2720 in grooves 2510 and/or on primary surface 2430 may vary according to various implementations of the invention. In some implementations of the invention, a single unit layer of modifying material 2720 (i.e., a layer having a thickness substantially equal to a single unit of modifying material 2720) may be layered onto appropriate surfaces 2710 of grooves 2510 and/or on primary surface 2430. In some implementations of the invention, two or more unit layers of modifying material 2720 may be layered into onto appropriate surfaces 2710 of grooves 2510 and/or on primary surface 2430.

[00153] Modified c-films 2700, 2800 (i.e., c-film 2400 modified with modifying material 2720) in accordance with various implementations of the invention may be useful for achieving one or more improved operational characteristics over those of unmodified c-film 2400.

[00154] As illustrated in Figure 29, in some implementations of the invention, primary surface 2430 of unmodified c-film 2400 may be modified, via a chemical etch, to expose or otherwise increase an area of appropriate surfaces 2710 available on primary surface 2430. In some implementations of the invention, one manner of characterizing an increased area of appropriate surfaces 2710 within primary surface 2430 may be based on the root mean square (RMS) surface roughness of primary surface 2430 of c-film 2400. In some implementations of the invention, as a result of chemical etching, primary surface 2430 of c-film 2400 may include an etched surface 2910 having a surface roughness in a range of about 1nm to about 50nm. RMS surface roughness may be determined using, for example, Atomic Force Microscopy (AFM), Scanning Tunneling Microscopy (STM), or SEM and may be based on a statistical mean of an R-range, wherein the R-range may be a range of the radius (r) of a grain size as would be appreciated. After the chemical etch, an etched surface 2910 of c-film 2900 may correspond to appropriate surface 2710 of ELR material 2410.

[00155] As illustrated in Figure 30, after the chemical etch, modifying material 2720 may be layered on to etched surface 2910 of c-film 2900 to form a modified c-film 3000. Modifying material 2720 may cover substantially all of surface 2910 and the thickness of modifying material 2720 may vary in accordance with various implementations of the invention. In some implementations of the invention, a single unit layer of modifying

material 2720 may be layered onto etched surface 2910. In some implementations of the invention, two or more unit layers of modifying material 2720 may be layered onto etched surface 2910.

[00156] In some implementations of the invention, films having orientations of crystalline structure of ELR material other than that of c-film 2400 may be used. For example, in reference to Figure 31, and according to various implementations of the invention, instead of the c-axis oriented perpendicular to primary surface 2430 as with c-film 2400, a film 3100 may have the c-axis oriented perpendicular to the principal axis 2440 and a b-axis of ELR material 3110 oriented perpendicular to primary surface 2430. Similarly, a film 3100 may have the c-axis oriented perpendicular to the principal axis 2440 and an a-axis of ELR material 3110 oriented perpendicular to primary surface 2430. In some implementations of the invention, film 3100 may have the c-axis oriented perpendicular to the principal axis 2440 and any line parallel to the c-plane oriented along principal axis 2440. As illustrated in Figure 31, in these implementations of the invention, film 3100 includes ELR material 3110 with the c-axis of its crystalline structure oriented perpendicular to principal axis 2440 and parallel to a primary surface 3130 and are generally referred to herein as a-b films 3100. While Figure 31 illustrates the other two axes of the crystalline structure in a particular orientation, such orientation is not necessary as would be appreciated. As illustrated, a-b films 3100 may include an optional substrate 2420 (as with c-films 2400).

[00157] In some implementations of the invention, a-b film 3100 is an a-film, having the c-axis of the crystalline structure of ELR material 3110 oriented as illustrated in Figure 31 and the a-axis perpendicular to primary surface 3130. Such a-films may be formed via various techniques including those described at Selvamanickam, V., et al., "High Current Y-Ba-Cu-O Coated Conductor using Metal Organic Chemical Vapor Deposition and Ion Beam Assisted Deposition," Proceedings of the 2000 Applied Superconductivity Conference, Virginia Beach, Virginia, September 17-22, 2000.

In some implementations, a-films may be grown on substrates 2420 formed of the following materials: LGSO, $LaSrAlO_4$, $NdCaAlO_4$, Nd_2CuO_4, or $CaNdAlO_4$. Other substrate materials may be used as would be appreciated.

[00158] In some implementations of the invention, a-b film 3100 is a b-film, having the c-axis of the crystalline structure of ELR material 3110 oriented as illustrated in Figure 31 and the b-axis perpendicular to primary surface 3130.

[00159] According to various implementations of the invention, primary surface 3130 of a-b film 3100 corresponds to an appropriate surface 2710. In some implementations that employ a-b film 3100, forming an appropriate surface of ELR material 3110 may include forming a-b film 3100. Accordingly, for implementations of the invention that include a-b film 3100, modifying material 2720 may be layered onto primary surface 3130 of a-b film 3100 to create a modified a-b film 3200 as illustrated in Figure 32. In some implementations of the invention, modifying material 2720 may cover primary surface 3130 of a-b film 3100 in whole or in part. In some implementations of the invention, the thickness of modifying material 2720 may vary as discussed above. More particularly, in some implementations of the invention, a single unit layer of modifying material 2720 may be layered onto primary surface 3130 of a-b film 3100; and in some implementations of the invention, two or more unit layers of modifying material 2720 may be layered onto primary surface 3130 of a-b film 3100. In some implementations of the invention, a-b film 3100 may be grooved or otherwise modified as discussed above with regard to c-film 2400, for example, to increase an overall area of appropriate surfaces 2710 of ELR material 3110 on which to layer modifying material 2720.

[00160] As would be appreciated, rather than utilizing a-b film 3100, some implementations of the invention may utilize a layer of ELR material 2410 having its crystalline structure oriented in a manner similar to that of a-b film 3100.

[00161] In some implementations of the invention (not otherwise illustrated) a buffer or insulating material may be subsequently layered onto modifying material 2720 of any of the aforementioned films. In these implementations, the buffer or insulating material and the substrate form a "sandwich" with ELR material 2410, 3110 and modifying material 2720 there between. The buffer or insulating material may be layered onto modifying material 2720 as would be appreciated.

[00162] Any of the aforementioned materials may be layered onto any other material. For example, ELR materials may be layered onto modifying materials. Likewise, modifying materials may be layered onto ELR materials. Further, layering may include combining, forming, or depositing one material onto the other material as would be appreciated. Layering may use any generally known layering technique, including, but not limited to, pulsed laser deposition, evaporation including coevaporation, e-beam evaporation and activated reactive evaporation, sputtering including magnetron sputtering, ion beam sputtering and ion assisted sputtering, cathodic arc deposition,

CVD, organometallic CVD, plasma enhanced CVD, molecular beam epitaxy, a sol-gel process, liquid phase epitaxy and/or other layering technique.

[00163] Multiple layers of ELR material 2410, 3110, modifying material 2720, buffer or insulating layers, and/or substrates 1120 may be arranged in various implementations of the invention. Figure 33 illustrates various exemplary arrangements of these layers in accordance with various implementations of the invention. In some implementations, a given layer may comprise a modifying material 2720 that also acts as a buffer or insulating layer or a substrate. Other arrangements or combinations of arrangements may be used as would be appreciated from reading this description. Furthermore, in some implementations of the invention, various layers of ELR material may have different orientations from one another in a given arrangement. For example, one layer of ELR material in an arrangement may have the a-axis of its crystalline structure oriented along the principal axis 2440 and another layer of the ELR material in the arrangement may have the b-axis of its crystalline structure oriented along the principal axis 2440. Other orientations may be used within a given arrangement in accordance with various implementations of the invention.

[00164] Figure 34 illustrates a process for creating a modified ELR material according to various implementations of the invention. In an operation 3410, an appropriate surface 2710 is formed on or within an ELR material. In some implementations of the invention where ELR material exists as ELR material 2410 of c-film 2400, appropriate surface 2710 is formed by exposing appropriate surface(s) 2710 on or within primary surface 2430 of a c-film 2400. In some implementations of the invention, appropriate surfaces of ELR material 2410 may be exposed by modifying primary surface 2430 using any of the wet or dry processing techniques, or combinations thereof, discussed above. In some implementations of the invention, primary surface 2430 may be modified by chemical etching as discussed above.

[00165] In some implementations of the invention where ELR material exists as ELR material 3110 of a-b film 3100 (with or without substrate 2420), appropriate surface 2710 is formed by layering ELR material 3110 (in a proper orientation as described above) onto a surface, which may or may not include substrate 2420.

[00166] In some implementations of the invention, appropriate surfaces 2710 include surfaces of ELR material parallel to the ab-plane. In some implementations of the invention, appropriate surfaces 2710 include faces of ELR material parallel to the b-plane. In some implementations of the invention, appropriate surfaces 2710 include

faces of ELR material parallel to the a-plane. In some implementations of the invention, appropriate surfaces 2710 include one or more faces of ELR material parallel to different ab-planes. In some implementations of the invention, appropriate surfaces 2710 include one or more faces not substantially perpendicular to the c-axis of ELR material.

[00167] In some implementations of the invention, various optional operations may be performed. For example, in some implementations of the invention, appropriate surfaces 2710 or ELR material may be annealed. In some implementations of the invention, this annealing may be a furnace anneal or a rapid thermal processing (RTP) anneal process. In some implementations of the invention, such annealing may be performed in one or more annealing operations within predetermined time periods, temperature ranges, and other parameters. Further, as would be appreciated, annealing may be performed in the chemical vapor deposition (CVD) chamber and may include subjecting appropriate surfaces 2710 to any combination of temperature and pressure for a predetermined time which may enhance appropriate surfaces 2710. Such annealing may be performed in a gas atmosphere and with or without plasma enhancement.

[00168] In an operation 3420, modifying material 2720 may be layered onto one or more appropriate surfaces 2710. In some implementations of the invention, modifying material 2720 may be layered onto appropriate surfaces 2710 using various layering techniques, including various ones described above.

[00169] Figure 35 illustrates an example of additional processing that may be performed during operation 3420 according to various implementations of the invention. In an operation 3510, appropriate surfaces 2710 may be polished. In some implementations of the invention, one or more polishes may be used as discussed above.

[00170] In an operation 3520, various surfaces other than appropriate surfaces 2710 may be masked using any generally known masking techniques. In some implementations, all surfaces other than appropriate surfaces 2710 may be masked. In some implementations of the invention, one or more surfaces other than appropriate surfaces 2710 may be masked.

[00171] In an operation 3530, modifying material 2720 may be layered on to (or in some implementations and as illustrated in Figure 35, deposited on to) appropriate surfaces 2710 using any generally known layering techniques discussed above. In some implementations of the invention, modifying material 2720 may be deposited on to appropriate surfaces 2710 using MBE. In some implementations of the invention, modifying material 2720 may be deposited on to appropriate surfaces 2710 using PLD.

In some implementations of the invention, modifying material 2720 may be deposited on to appropriate surfaces 2710 using CVD. In some implementations of the invention, approximately 40 nm of modifying material 2720 may be deposited on to appropriate surfaces 2710, although as little as 1.7 nm of certain modifying materials 2720 (e.g., cobalt) has been tested. In various implementations of the invention, much smaller amounts of modifying materials 2450, for example, on the order of a few angstroms, may be used. In some implementation of the invention, modifying material 2720 may be deposited on to appropriate surfaces 2710 in a chamber under a vacuum, which may have a pressure of 5x10-6 torr or less. Various chambers may be used including those used to process semiconductor wafers. In some implementations of the invention, the CVD processes described herein may be carried out in a CVD reactor, such as a reaction chamber available under the trade designation of 7000 from Genus, Inc. (Sunnyvale, Calif.), a reaction chamber available under the trade designation of 5000 from Applied Materials, Inc. (Santa Clara, Calif.), or a reaction chamber available under the trade designation of Prism from Novelus, Inc. (San Jose, Calif.). However, any reaction chamber suitable for performing MBE, PLD or CVD may be used.

[00172] Figure 36 illustrates a process for forming a modified ELR material according to various implementations of the invention. In particular, Figure 36 illustrates a process for forming and/or modifying an a-b film 3100. In an optional operation 3610, a buffer layer is deposited onto a substrate 2420. In some implementations of the invention, the buffer layer includes PBCO or other suitable buffer material. In some implementations of the invention, substrate 2420 includes LSGO or other suitable substrate material. In an operation 3620, ELR material 3110 is layered onto substrate 2420 with a proper orientation as described above with respect to Figure 31. As would be appreciated, depending on optional operation 3610, ELR material 3110 is layered onto substrate 2420 or the buffer layer. In some implementations of the invention, the layer of ELR material 3110 is two or more unit layers thick. In some implementations of the invention, the layer of ELR material 3110 is a few unit layers thick. In some implementations of the invention, the layer of ELR material 3110 is several unit layers thick. In some implementations of the invention, the layer of ELR material 3110 is many unit layers thick. In some implementations of the invention, ELR material 3110 is layered onto substrate 2420 using an IBAD process. In some implementations of the invention, ELR material 3110 is layered onto substrate 2420 while subject to a magnetic field to improve an alignment of the crystalline structures within ELR material 3110.

[00173] In an optional operation 3630, appropriate surface(s) 2710 (which with respect to a-b films 3100, corresponds to primary surface 3130) of ELR material 3110 is polished using various techniques described above. In some implementations of the invention, the polishing is accomplished without introducing impurities onto appropriate surfaces 2710 of ELR material 3110. In some implementations of the invention, the polishing is accomplished without breaking the clean chamber. In an operation 3640, modifying material 2720 is layered onto appropriate surfaces 2710. In an optional operation 3650, a covering material, such as, but not limited to, silver, is layered over entire modifying material 2720.

[00174] In various implementations of the invention, modified ELR materials 1060, whether used in bulk, incorporated into films (e.g., ELR material 2410 in c-film 2400, ELR material 3110 in a-b film 3100, or other films or tapes), or utilized in other ways (e.g., wires, foils, nanowires, etc.), may be incorporated into various products, systems and/or devices as described herein.

[00175] While various implementations of the invention are described below in terms of "modified" ELR materials, various implementations may include new ELR materials with improved operating characteristics without departing from the scope of the invention as would be appreciated. Furthermore, various implementations may include any materials exhibiting some or all of the improved operating characteristics described herein without departing from the scope of the invention as would be appreciated. That is, various implementations may include modified ELR materials, apertured ELR materials, non-conventional ELR materials, and/or other materials that exhibit some or all of the improved operating characteristics described herein. In various implementations, the ELR materials described herein, such as the modified ELR materials and/or the apertured ELR materials, may be part of or formed into a number of different current carrying components, such as films/tapes, wires, nanowires, and so on, to be used in devices, systems, and other implementations of the invention. The following are a few examples current carrying components, although one of ordinary skill will appreciate that others may also be utilized:

[00176] Nanowires - nanostructures that have widths or diameters on the order of tens of nanometers or less and generally unconstrained lengths, used to form segments, contours, coils, and/or other structures capable of carrying current from one point to another with extremely low resistance. Nanostructures may be formed into a variety of

nanowire configurations including discrete structures, integrated on or into a substrate, implemented on or into a supporting structure, and other nanowire configurations;

[00177] Foils – configuring ELR material on or into flexible films/tapes, such as, but not limited to metal tapes, and optionally coating the metal and/or ELR material with buffering metal oxides. Texture may be introduced into the tape, such as by using a rolling-assisted, biaxially-textured substrates (RABiTS) process, or a textured ceramic buffer layer may instead be deposited, with the aid of an ion beam on an untextured alloy substrate, such as by using an ion beam assisted deposition (IBAD) process. Other techniques may utilize chemical vapor deposition CVD processes, physical vapor deposition (PVD) processes, molecular beam epitaxy (MBE), Atomic-Layer-By-Layer molecular beam epitaxy (ALL-MBE), and other solution deposition techniques to produce ELR tapes;

[00178] Wires – one or more ELR components may be sandwiched together to form a macroscale wire; and other current carrying components.

[00179] Thus, in some implementations, forming and/or integrating the ELR materials described herein into various current carrying components enables and/or facilitates the implementation of the ELR materials into devices and systems that utilize, generate, transform and/or transport electric energy, such as electric current. These devices and systems may benefit from the improved operating characteristics by operating more efficiently in comparison to conventional devices and systems, operating more cost-effectively in comparison to conventional devices and systems, operating less wastefully in comparison to conventional devices and systems, and other improved operating characteristics.

Layered Compositions that Exhibit Extremely Low Resistance

[00180] This section of the description refers to Figure 1-Z through Figure 7-Z; accordingly all reference numbers included in this section refer to elements found in such figures.

[00181] For purposes of this description and according to various implementations of the invention, the compositions of matter generally include an ELR material, such as, but not limited to, a perovskite material (e.g., YBCO, etc.), and a modifying material or modifying component (referenced interchangeably) such as: one or more layers of modifying component externally applied to the ELR material; one or more modifying components that facilitate application of a strain within the ELR material; one or more layers of differing ELR materials, one or more of which facilitate application of a strain within the

ELR material of another layer(s); one or more layers of the ELR material having different crystal orientations, one or more of which facilitate application of a strain within the ELR material of another layer(s); one or more modifying components that facilitate a strain within the ELR material; one or more modifying components such as described above; and/or other modifying components.

[00182] In some implementations, the compositions of matter may include one or more modifying components applied to or formed on the ELR material within a certain proximity to a charge plane and/or charge reservoir of the ELR material. For example, a composition of matter may include a layer of YBCO and a layer of modifying material that is applied to or formed on an appropriate surface of the layer of YBCO. In some implementations, this surface is substantially parallel to a c-axis of the YBCO. In some implementations, this surface is substantially perpendicular to an a-axis of the YBCO. In some implementations, this surface is substantially perpendicular to a b-axis of the YBCO. In some implementations, other appropriate surfaces may be used.

[00183] In some implementations, application of the modifying component to the ELR material may cause one or more oxygen atoms within a crystalline structure of the ELR material to move within the ELR material, forming an oxygen concentration gradient that strains the crystalline structure of the ELR material. In some implementations, a modifying component, such as chromium, may act as a "getter" for the oxygen atoms within the ELR material, thereby causing the oxygen atoms to move towards the modifying component, which in turn strains various areas within or portions of the crystalline structure of the ELR material.

[00184] In some implementations, a composition of matter may include multiple layers of different ELR materials, such different ELR materials including different atoms, including but not limited to, differing rare earth metal atoms, with respect to one another (e.g., YBCO vs. DyBCO, YBCO vs. NBCO, DyBCO vs. NBCO, etc.); different oxygen content within their crystalline structures with respect to one another (e.g., the oxygen stoichiometry/fraction in YBCO between O_6 and O_7); and/or different crystalline orientation with respect to one another (e.g., a-axis YBCO vs. b-axis YBCO, etc.). Such compositions may be layered in a fashion such that the differing layers of ELR materials may strain various areas within or portions of the composition.

[00185] In some implementations of the invention, the strains within various areas or portions of the composition impact apertures in the crystalline structures of the ELR

material so as to improve the operating characteristics (e.g., operating temperature, current carrying capacity, etc.) of the ELR material.

[00186] Modification of a material, such as a material having a crystalline structure, may cause the material to exhibit lower resistance, such as extremely low resistance, to current within the material at higher than expected temperatures. In some implementations, the modification may include applying or forming a layer of modifying material onto an appropriate surface as discussed above. The applied or formed layer of modifying material may cause a strain or otherwise apply a force to some or all of the atoms and/or bonds that make up the crystalline structure of the material. This force or strain may alter the material such that the material exhibits different resistance characteristics, such as lower resistance or extremely low resistance. That is, causing a force or strain within the material may: cause the material to generate, exhibit, and/or maintain a certain oxygen diffusion gradient at certain locations and/or areas within the material; cause the material to generate, exhibit, and/or maintain a certain level of oxygen diffusion within or proximate to a charge reservoir within the material; and/or cause the crystalline structure of the material to twist, warp, open, close, stiffen, or otherwise maintain or change orientation and/or geometry, such as maintain or change geometry with respect to apertures within the material that may facilitate the transport of electrons from one location to another; and so on.

[00187] Various implementations of the invention may facilitate the application of forces or strains to or within an ELR material. In some implementations, the forces may be externally and/or non-invasively applied to various portions of the ELR material. In some implementations, the forces may result in internal stresses, strains or other forces applied within various portions of the ELR material. For example, the portions may be a portion of the ELR material that includes oxygen atoms, a portion of the ELR material that includes a copper-oxygen plane of atoms, a portion of the ELR material that includes a reservoir of charges, a portion of the ELR material that includes an aperture within the crystalline structure of the ELR material, a portion of the ELR material that corresponds to (i.e., substantially parallel with) an a-plane of the material, a portion of the ELR material that corresponds to (i.e., substantially parallel with) a b-plane of the material, a portion of the ELR material that corresponds to a plane substantially parallel to a c-axis the material, a portion of the ELR material that is located near or proximate to a surface of the material, or other portion of the ELR material.

[00188] Using the various observations described herein, various implementations of the invention may be realized as various compositions of matter, which are now described in detail.

[00189] Various implementations of the invention may comprise various compositions, such as compositions having ELR materials and modifying materials, configured and/or adapted to carry current from one location to another. That is, such compositions conduct electrons from one location to another, among other things.

[00190] In some implementations, various compositions comprise one or more modifying materials applied to or formed on appropriate surfaces of an ELR material. Figure 1-Z illustrates a composition 100 of a modified ELR material (also referred to herein as a modified ELR material 100), having an ELR material 110 (also referred to herein as an unmodified ELR material 110) and a modifying material 120 applied to a surface of the ELR material 110.

[00191] In some implementations, the ELR material 110 may be a representative of a family of superconducting materials commonly referred to as mixed-valence cuprate perovskites as discussed above. Such mixed-valence cuprate perovskite materials may also include, but are not limited to, various substitutions of the cations of the materials. The aforementioned named mixed-valence cuprate perovskite materials may refer to generic classes of materials in which many different formulations exist, such as a class of perovskite materials that include a rare earth metal (Re), Barium (Ba), Copper (Cu), and Oxygen (O), or "ReBCO." Example ReBCO materials may include YBCO, NBCO, HoBCO, GdBCO, DyBCO, and others, such as others having a suitable 1-2-3 stoichiometry.

[00192] In some implementations, the ELR material 110 may include an HTS material outside of the family of mixed-valence cuprate perovskite materials ("non-perovskite materials"). Such non-perovskite materials may include, but are not limited to, iron pnictides, magnesium diboride (MgB_2), and other non-perovskites. In some implementations, the ELR material 110 may be other superconducting materials or non-superconducting materials.

[00193] In some implementations, the modifying material 120 may be a metal, such as chromium, copper, bismuth, cobalt, vanadium, titanium, rhodium, or beryllium, or metal oxides of such metals. In some implementations, the modifying material 120 may be any material capable of applying strain to or within the ELR material 110, such as a metal having a high oxygen affinity, a "getter" material, a material (including another ELR

material) having one or more lattice constants different from those of the ELR material 110, and so on. For example, in some implementations, the modifying material 120 may have a strong oxygen affinity, such as a material that readily bonds to, attracts, or "gets," oxygen or changes the oxygen content and/or oxygen distribution within the ELR material in order to cause a strain within the ELR material 110. In some implementations, modifying material 120 may have one or more lattice constants that is mismatched with those of the ELR material 110 in order to cause a strain within the ELR material 110.

[00194] For example, one effect of depositing a modifying material 120 of chromium on the surface of the ELR material 110 may be to create an oxygen gradient near the surface of the ELR material 110. In some implementations, the modifying layer 120 is placed onto surfaces of the ELR material substantially perpendicular to the a-axis or the b-axis of the ELR material, which may result in the creation of the oxygen concentration gradient, among other things, within the ELR material. In some implementations, the modifying layer 120 is placed onto surfaces of the ELR material substantially parallel to the c-axis of the ELR material, which may result in the creation of the oxygen concentration gradient, among other things, within the ELR material.

[00195] In some implementations, the ELR material 110 includes a charge plane that includes one or more atoms that, in part, form the aperture. For example, YBCO is formed of various atoms of yttrium ("Y"), barium ("Ba"), copper ("Cu") and oxygen ("O"). Apertures within YBCO are formed by aperture atoms, namely atoms of yttrium, copper, and oxygen, and charge planes within YBCO are formed by various atoms of copper ("Cu") and oxygen ("O").

[00196] Figure 2-Z illustrates a composition 200 that includes a substrate 230, two or more modifying components 210, 215 and an ELR material 220, located between the modifying components 210, 215. In particular, the modifying components 210, 215 are bonded to or formed on a top surface and a bottom surface, respectively, of the ELR material 220. In some implementations of the invention, the top and bottom surfaces of the ELR material 220 are appropriate surfaces of the ELR material 220 (e.g., surfaces substantially perpendicular to an a-axis of the ELR material 220, etc.) The composition 200, therefore, may be strained proximate to the top surface of the ELR material 220 by the modifying component 210 and strained proximate to the bottom surface of the ELR material 220 by the modifying component 215 located on the substrate 230.

[00197] By applying modifying material(s) to one or more surfaces of the ELR material, various implementations of the invention may control the application of the strain and/or

may strain the ELR material at various locations of the ELR material, such as at one or more locations having charge planes, at one or more unit cells of the ELR material, at one or more apertures of the ELR material, and/or other locations.

[00198] Some implementations of the invention may comprise a superlattice of layers of ELR material(s) which may act to enhance the properties of one or more of the layers of ELR material of the superlattice.

[00199] Figure 3-Z is a block diagram of a composition 300 that includes layers of different ELR materials according to various implementations of the invention. More specifically, composition 300 includes a first layer 310 of ELR material referenced as "ELR-X" and a second layer 320 of ELR material referenced as "ELR-Y." As illustrated in Figure 3-Z, first layer 310 is formed on or applied to a substrate 330 and second layer 320 is formed on or applied to first layer 310. As would be appreciated, in some implementations of the invention, substrate 330 is optional. While illustrated as only having first layer 310 and second layer 320, composition 300 may comprise any number of pairs of first layer 310 and second layer 320 formed in a pattern alternating between first layer 310 and second layer 320. In some implementations, ELR-X corresponds to a first ELR material and ELR-Y corresponds to a second ELR material different from the first ELR material. For example, in some implementations of the invention, ELR-X may correspond to YBCO and ELR-Y may correspond to NBCO. Other ELR materials may be used as would be appreciated.

[00200] Figure 4-Z is a block diagram of a composition 400 that includes layers of different forms of the same ELR material according to various implementations of the invention. More specifically, composition 400 includes a first layer 410 of a first form of the ELR material referenced as "ELR-X Form 1" and a second layer 420 of a second form of the same ELR material referenced as "ELR-X Form 2." In some implementations, the same basic ELR material has different forms, such as, but not limited to, different crystalline orientations, different oxygen stoichiometry/fractions (e.g., O_6 and O_7 in YBCO, etc.), different variants, and other different forms. Other forms of the same ELR materials may be used as would be appreciated. As illustrated, first layer 410 is formed on or applied to a substrate 430 and second layer 420 is formed on or applied to first layer 410. As would be appreciated, in some implementations of the invention, substrate 430 is optional. While illustrated as only having first layer 410 and second layer 420, composition 400 may comprise any number of pairs of first layer 410 and second layer 420 formed in a pattern alternating between first layer 410 and second layer 420.

[00201] As discussed, the composition 400 may include layers of different forms or variant of the same ELR material (e.g., ReBCO) and these different forms of the same ELR material may cause strain to or within one or more layers of the ELR material. For example, varying the oxygen content between layers (e.g., changing the oxygen stoichiometry/fraction in YBCO between O_6 and O_7) may cause lattice mismatches between layers, which may strain the bonds of the crystalline structures of the ELR materials within the layers. Also for example, varying the crystal orientation of the ELR material between layers (e.g., one layer of the ELR material has an a-axis orientation while another layer of the ELR material has a b-axis orientation) may also cause lattice mismatch between the layers, thereby causing similar strain.

[00202] Figure 5-Z depicts a composition 500 that includes layers of a plurality of different ELR materials. As illustrated, the composition 500 includes a first layer 510 of ELR material referenced as "ELR-X", a second layer 520 of ELR material referenced as "ELR-Y", and a third layer 530 of ELR material referenced as "ELR-Z". As illustrated, first layer 530 is formed on or applied to a substrate 540, second layer 510 is formed on or applied to first layer 530, and third layer 520 is formed on or applied to second layer 510. As would be appreciated, in some implementations of the invention, substrate 530 is optional. In some implementations of the invention, the ELR materials included in the layers of composition 500 may be different ELR materials altogether (as discussed above with reference to Figure 3-Z) or different forms of the same ELR material (as discussed above with reference to Figure 4-Z).

[00203] While not otherwise illustrated in Figures 3-Z – 5-Z, various other layers of non-ELR materials may be included in various compositions 300, 400, 500 (or any of the other compositions described herein) including layers interspersed between one of more of the layers illustrated in Figure 5-Z.

[00204] Creating compositions 300, 400, 500 that are formed of layers of different ELR materials or different forms of ELR materials, enables various implementations of the invention to utilize lattice mismatches between various ReBCO materials (e.g., YBCO and NBCO, among others), or other materials having similar lattice parameters (e.g., BSCCO and others) in order to stress/strain various ones of the layers of ELR materials. In some implementations, the added strains may a change the phonon frequency and/or distribution and/or amplitude around the apertures in the crystalline structure of these ELR materials, allowing for drops in the resistance of the materials, improved operating

characteristics such as, but not limited to operating in an ELR state at higher temperatures, and other benefits.

[00205] In some implementations of the invention, the layers of the superlattice of compositions 300, 400, 500 are formed such that appropriate surfaces of the ELR material (e.g., surfaces substantially perpendicular to an a-axis of the ELR material, surfaces substantially perpendicular to a b-axis of the ELR material, surfaces substantially parallel to a c-axis of the ELR material, etc.) in the layers correspond to the interface surfaces between the ELR materials. In other words, the surface forming the interface between layers 520 and 510 of Figure 5-Z, for example, corresponds to a surface that is substantially perpendicular to the a-axis of both ELR-Y and ELR-X, that is substantially perpendicular to the b-axis of both ELR-Y and ELR-X, or that is otherwise substantially parallel to the c-axis of both ELR-X and ELR-Y.

[00206] Of course, there may be many layers of similar and/or different ELR materials within the compositions of various implementations of the invention. In some implementations, the composition 500 may be formed by depositing a layer having a first thickness of a first ReBCO material, then depositing a layer having a second thickness of a second ReBCO material, and then depositing a layer having a third thickness of a third ReBCO material, where at least the ReBCO material of the second layer has one or more lattice constants different from those of the materials of the first and third layers. In addition, the first, second and third thicknesses may be the same as one another, entirely different from one another, or the same as some and different from others, etc. Any number of different ReBCO layers and/or thicknesses of the layers may be deposited in order to improve operating characteristics of the compositions, including, but not limited to, improving various temperature, resistance and/or current carrying capacities of the composition, among other things.

[00207] In some implementations of the invention, the composition may be layered as follows (bottom to top):

$$ELR_1 : ELR_2 : ELR_1 : ELR_2 : ELR_1 : ELR_2 : ELR_1 : ELR_2 : \& .$$

[00208] In some implementations of the invention, the composition may be layered as follows (bottom to top):

$$ELR_1 : ELR_2 : ELR_3 : ELR_4 : ELR_3 : ELR_2 : ELR_1 : ELR_2 : ELR_3 : \& .$$

[00209] In some implementations of the invention, the composition may be layered as follows (bottom to top):

$$ELR_1 : ELR_2 : ELR_3 : ELR_4 : ELR_3 : ELR_4 : ELR_3 : ELR_4 : ELR_3 : \& .$$

[00210] In some implementations of the invention, the composition 500 may be layered as follows (bottom to top):

$$ELR_1 : ELR_2 : ELR_3 : ELR_2 : ELR_3 : ELR_2 : ELR_3 : ELR_2 : ELR_3 : \& .$$

[00211] Thus, the layers may be chosen for a variety of reasons, such as to create a mismatch of lattice constants, to create a controlled strain within one or more layers, to increase current carrying capacity of the composition, to improve manufacturing of the compositions, to improve the manufacturability of the layers onto one another, and so on. In addition, the thickness of the layers, such as the number of unit cells of material per layer, may be chosen to adjust the strain on a layer, to increase the current carrying capacity, and so on.

[00212] In some implementations of the invention, the number of layers, the type of ELR material within one or more layers, the type of other, non-ELR material within one or more layers, the thickness of one or more layers, the orientation of one or more layers, the sequence of one or more layers, and/or other parameters of a composition may be modified, defined, and/or chosen to achieve desired characteristics for the composition or the manufacturability of the composition, among other benefits.

[00213] Figure 6-Z depicts an example composition 600 formed of superlattice comprising a plurality of layers of various ELR materials according to various implementations of the invention. As illustrated in Figure 6-Z, the composition 600 comprises a LaSrGaO4 (LSGO) substrate 610, having a top surface substantially perpendicular to an a-axis of the substrate. Other substrates may be used such as, but not limited to, strontium titanate (STO) or magnesium oxide (MgO). A layer 620 of YBCO is formed on the substrate 610, followed by alternating a layer 634 of NBCO with a layer 632 of YBCO. By way of example, composition 600 may comprise a layer 620 of YBCO formed with a thickness of 200 nm, followed by ten (10) pairs of alternating layers 634, 632 of NBCO and YBCO, respectively, each of such alternating layers having a thickness of 10 nm (i.e., 10nm of NBCO alternating with 10nm of YBCO) formed on the YBCO layer 620. Although not otherwise illustrated, the composition 600 may include other layers, such as layers of buffer material, additional or fewer pairs of alternating layers, additional layers of other ELR materials, additional or other substrate layers, layers of other or differing thicknesses, and so on.

[00214] In some implementations of the invention, a barrier material may be used to substantially encase various compositions described above. The barrier material may be used to substantially prevent oxygen in the crystalline structures of the ELR materials

from diffusing out of the composition. In some implementations, gold may be deposited onto all surfaces of the composition to substantially encase the composition. Other barrier materials such as, but not limited, to silicon dioxide or indium tin oxide (ITO) may be used. In some implementations, 5-10nm of gold is deposited onto all the surfaces of the composition, although other thicknesses may be used.

[00215] Figures 7A-Z - 7I-Z illustrate test results obtained from testing a sample of composition of an LSGO substrate; followed by approximately 200nm of YBCO formed with an a-axis orientation on the LSGO substrate (e.g., a-axis of the YBCO up); followed by 10 pairs of alternating layers of approximately 10nm of NBCO and approximately 10nm of YBCO, each of these layers formed with an a-axis orientation on the prior layer; and followed by approximately 8.5nm of gold as a barrier material encasing the sample.

[00216] The test results of Figures 7A-Z - 7I-Z include relevant portions of plots of resistance of the sample as a function of temperature (in Kelvin) over various runs and conditions as described below. More particularly, the plots correspond to measurements of the resistance of the sample over a temperature range of 180K-270K. Before describing the test results in further detail, a brief description of the testing equipment and setup is provided.

[00217] The sample was mounted on a PCB board using double-side tape. Tinned copper wires having a diameter of 0.004" were attached to the top gold surface of the sample with indium solder. The opposite ends of these wires were attached to pads on the PCB board. This assembly was placed in a cryostat. A Keithley 6221 current source provided a DC current through the sample while a Keithley 2182a voltmeter measured the voltage drop across the sample to provide a "delta-mode" resistance measurement (e.g., R = ((V+) - (V-)) / 2 *I)). Resistive thermal devices ("RTDs") were used to measure temperature.

[00218] For some of the test runs, the sample was initially cooled to a temperature below the transition temperature of YBCO and allowed to warm. For other tests runs (to save time and coolant, and also to avoid thermally stressing the sample unnecessarily), the sample was only cooled to just below160K and allowed to warm. In either case, as the sample warmed, measurements of the voltage across the sample were obtained along with measurements of the sample's temperature. From the voltage measurements, the delta-mode resistances were determined and subsequently plotted as resistance versus temperature, or R(T) curves (also sometimes referred to as R-T profiles), corresponding to the test results illustrated in the Figures 7A-Z - 7I-Z.

[00219] Figures 7A-Z to 7H-Z correspond to the individual R(T) curves of eight test runs of the sample, in the order in which the test runs were conducted (i.e., Figure 7A-Z corresponds to the R(T) curve for the first test run, Figure 7B-Z corresponds to the R(T) curve for the second test run, etc.) Figures 7A-Z - 7D-Z and 7H-Z correspond to the R(T) curves for test runs where the sample was driven by 200nA of DC current. Figures 7E-Z - 7G-Z correspond to the R(T) curves for test runs where the sample was driven by 100nA of DC current. Other than the determination of the delta-mode resistance form the voltage measurement, no other smoothing, averaging or other data processing was used.

[00220] Figure 7I-Z corresponds to the R(T) curve of a single test run of the sample in a different test bed and under different conditions of those of Figures 7A-Z - 7H-Z. In particular, during this test run, a SR830 lock-in amplifier (LIA) was employed, and the sample was driven by 200nA of AC current at 24Hz, using a 1 second time constant.

[00221] As illustrated, all of the test runs include one or more changes in the respective R(T) curve in roughly the range of 210K-240K. These changes in the slope of the R(T) curve are believed to be consistent with portions of the sample entering a reduced resistance or ELR state. As would be appreciated, similar changes are not observed in either the R(T) curves of YBCO or NBCO.

[00222] Some implementations of the invention may comprise alternating layers having thicknesses greater or less than those described above with regard to Figure 6-Z. In some implementations of the invention, at least one of the layers in the superlattice may be one, two, three or more unit cells thick. In some implementations of the invention, each of the layers in the alternating pair of layers in the superlattice may be one, two, three or more unit cells thick. In some implementations of the invention, a thickness of one layer in a pair (or other grouping) of alternating layers is different from a thickness of the other layer in the pair. In some implementations of the invention, a thickness of the layers of one pair of alternating layers in the superlattice differs from a thickness of the layers of another pair of alternating layers in the superlattice. Other thicknesses may be used as would be appreciated to achieve various operational characteristics as discussed herein.

[00223] Some implementations of the invention may comprise multiple Re atoms within a single layer, such as a layer having multiple Re atoms with different sizes with respect to one another. For example, a ReBCO layer may have a lattice structure where 4 out of every 5 Re atoms is a Y atom, and every 5^{th} atom is a Dy atom. These types of layers,

which include two or more rare earth atoms within their crystalline structures, may introduce additional strain forces within a composition due to ordering effects, localized lattice mismatches, additional vibrational constants, and so on.

[00224] Some implementations of the invention may comprise Re atoms which are selected based on their oxidation states. For example, although Y and Nd have one oxidation state (3^+), the elements Samarium (Sm), Europium (Eu), Erbium (Er), Thulium (Tm), and Ytterbium (Yb) may have two oxidation states of 3^+ and 2^+, and Cesium (Ce) and Terbium (Tb) may have two oxidation states of 3^+ and 4^+. Other Re atoms with other oxidation states may be selected as would be appreciated. In such implementations, Re atoms with variable oxidation states in an ELR layer of a composition may assist in fixing oxygen sites and/or carrier defects within a crystalline structure or aperture of the crystalline structure, and/or may stabilize a local amount of more or less oxygen in a certain layer, among other benefits. For example, a layer of ELR material within a superlattice may include mostly Y atoms as the Re atoms, along with a few Ce 3^+ atoms and a few Ce 4^+ atoms to be used in controlling the oxygen/carrier defects within such layer, among other things.

[00225] In some implementations of the invention, a layer of material having a very low oxygen affinity (e.g., gold) is formed on an outermost layer of ELR material in the superlattice to reduce a rate at which oxygen diffuses out of or into various ones of the layers of the superlattice. In some implementations of the invention, a layer of material having a very low oxygen affinity (e.g., gold) is formed on all outermost surfaces of the superlattice to reduce a rate at which oxygen diffuses out of or into various ones of the layers of the superlattice.

[00226] In some implementations of the invention, various manufacturing processes used in creating a superlattice of layers of ELR material may introduce a desired strain into a material. For example, when depositing layers of ELR material on a substrate, varying a temperature of the substrate and/or the oxygen partial pressures during the depositions may allow the materials to be deposited at their "natural" temperature, and strain would be introduced as the materials cool below the deposition temperatures, among other things.

[00227] Thus, some implementations of the invention may comprise a superlattice, where, in effect, each layer within the superlattice may act to modify adjoining layers, among other things. In other word, a layer may correspond to both an ELR material in and of itself, and as a modifying material to another layer of ELR material, such that

layers within the superlattice together form a modified ELR material. According to various implementations of the invention, a composition of various different layers of ELR material, varying in type, oxygen content, Re atom type, orientation, and so on, may provide sufficient strain to one or more layers of the composition such that these layers exhibit lower or extremely low resistance to current carried within or between the layers, among other benefits.

[00228] According to various implementations of the invention, the compositions 100, 200, 300, 400, 500, and/or 600 of this section, whether used in bulk, incorporated into films or tapes, or utilized in other ways (e.g., wires, foils, nanowires, and so on) may be incorporated into various apparatuses and associated devices, as described herein. For example, the compositions may be utilized by and/or incorporated into capacitors, inductors, transistors, conductors and conductive elements, integrated circuits, antennas, filters, sensors, magnets, medical devices, power cables, energy storage devices, transformers, electrical appliances, mobile devices, computing devices, information storage devices, and other devices and systems that transfer electrons and/or information when in use.

[00229] Thus, in some implementations, forming and/or integrating the modified ELR materials described herein into various current carrying components enables and/or facilitates the implementation of the modified ELR materials into devices and systems that utilize, generate, transform and/or transport electric energy, such as electric current. These devices and systems may benefit from the improved operating characteristics by operating more efficiently in comparison to conventional devices and systems, operating more cost-effectively in comparison to conventional devices and systems, operating less wastefully in comparison to conventional devices and systems, and so on.

[00230] In some implementations, a composition of matter comprises a first layer of ELR material having a crystalline structure; and a second layer of material formed on the first layer that applies a strain within at least a portion of the crystalline structure of the ELR material. In some implementations, the second layer of material applies a controlled strain within at least a portion of a crystalline structure of the ELR material. In some implementations, the second layer of material applies a strain within a location of the crystalline structure of the ELR material that includes a charge plane. In some implementations, the second layer of material applies a strain within a location of the crystalline structure of the ELR material that includes an aperture of the crystalline structure.

[00231] In some implementations, a composition that conducts current, comprises a first layer of ELR material having a copper oxide charge plane; and a second layer of material formed on the first layer that induces a strain within at least a portion of the first layer of ELR material that contains the copper oxide charge plane. In some implementations, the second layer of material induces an external strain to the at least of the first layer of ELR material. In some implementations, the second layer of material induces an internal strain within the at least of the first layer of ELR material. In some implementations, the second layer of material induces a diffusion of oxygen atoms within the first layer of ELR material. In some implementations, the second layer of material induces a diffusion gradient of oxygen atoms within the first layer of ELR material.

[00232] In some implementations, a composition comprises a conductive material having a crystalline structure; and a material formed on the conductive material that causes a force to be applied to or within a portion of the crystalline structure of the conductive material. In some implementations, the conductive material is a rare earth copper oxide material, and the material that causes a force to be applied to a portion of the crystalline structure of the conductive material is a metal having a high oxygen affinity.

[00233] In some implementations, a composition comprises a first ELR material having a crystalline structure; and a second ELR material formed on the first ELR material, the second ELR material causing a force within a portion of the crystalline structure of the first ELR material.

[00234] In some implementations, a composition comprises a first ELR material; and a second ELR material having a crystalline structure, the second ELR material formed on the first ELR material, the first ELR material causing a force within a portion of the crystalline structure of the second ELR material.

[00235] In some implementations, a composition comprises a first ELR material having a crystalline structure; and a second ELR material having a crystalline structure, the second ELR material formed on the first ELR material, the second ELR material causing a force within a portion of the crystalline structure of the first ELR material and the first ELR material causing a force within a portion of the crystalline structure of the second ELR material.

[00236] In some implementations, a composition comprises a first layer of an ELR material having a first form; a second layer of the ELR material having a second form,

wherein the second layer is formed on the first layer; and a third layer of the ELR material having the first form, wherein the third layer is formed on the second layer.

[00237] In some implementations, a composition comprises a first layer of YBCO; and a plurality of layers formed on a top surface of the YBCO, the plurality of layers comprising pairs of alternating layers of NBCO and YBCO. In some implementations, a thickness of the first layer of YBCO is approximately 200 nanometers and a thickness of each of the layers within the plurality of layers is approximately 10 nanometers. In some implementations, the plurality of layers comprises ten pairs of alternating layers of NBCO and YBCO. In some implementations, the plurality of layers comprises at least two pairs of alternating layers of NBCO and YBCO.

[00238] In some implementations, a composition for propagating current, the composition comprises a plurality of layers comprising at least one pair of alternating layers of NBCO and YBCO. In some implementations, the group of layers comprises at least ten pairs of alternating layers of NBCO and YBCO. In some implementations, a substrate having a surface substantially perpendicular to an a-axis of the substrate; a layer of YBCO applied to the surface of the substrate, the layer of YBCO having a surface substantially perpendicular to an a-axis of the YBCO; and wherein the group of layers are applied to the surface of the YBCO.

[00239] In some implementations, a composition comprises a base layer of YBCO, the base layer having a surface substantially parallel to a c-axis of the YBCO; a first layer of NBCO formed on the surface of the base layer of YBCO, the first layer of NBCO having a surface substantially parallel to a c-axis of the NBCO; a first layer of YBCO formed on the surface of the first layer of NBCO, the first layer of YBCO having a surface substantially parallel to a c-axis of the YBCO; a second layer of NBCO formed on the surface of the first layer of YBCO, the second layer of NBCO having a surface substantially parallel to a c-axis of the NBCO; a second layer of YBCO formed on the surface of the second layer of NBCO, the second layer of YBCO having a surface substantially parallel to a c-axis of the YBCO; a third layer of NBCO formed on the surface of the second layer of YBCO, the third layer of NBCO having a surface substantially parallel to a c-axis of the NBCO; a third layer of YBCO formed on the surface of the third layer of NBCO, the third layer of YBCO having a surface substantially parallel to a c-axis of the YBCO; a fourth layer of NBCO formed on the surface of the third layer of YBCO, the fourth layer of NBCO having a surface substantially parallel to a c-axis of the NBCO; a fourth layer of YBCO formed on the surface of the fourth layer of

NBCO, the fourth layer of YBCO having a surface substantially parallel to a c-axis of the YBCO; a fifth layer of NBCO formed on the surface of the fourth layer of YBCO, the fifth layer of NBCO having a surface substantially parallel to a c-axis of the NBCO; a fifth layer of YBCO formed on the surface of the fifth layer of NBCO, the fifth layer of YBCO having a surface substantially parallel to a c-axis of the YBCO; a sixth layer of NBCO formed on the surface of the fifth layer of YBCO, the sixth layer of NBCO having a surface substantially parallel to a c-axis of the NBCO; a sixth layer of YBCO formed on the surface of the sixth layer of NBCO, the sixth layer of YBCO having a surface substantially parallel to a c-axis of the YBCO; a seventh layer of NBCO formed on the surface of the sixth layer of YBCO, the seventh layer of NBCO having a surface substantially parallel to a c-axis of the NBCO; a seventh layer of YBCO formed on the surface of the seventh layer of NBCO, the seventh layer of YBCO having a surface substantially parallel to a c-axis of the YBCO; an eighth layer of NBCO formed on the surface of the seventh layer of YBCO, the eighth layer of NBCO having a surface substantially parallel to a c-axis of the NBCO; an eighth layer of YBCO formed on the surface of the eighth layer of NBCO, the eighth layer of YBCO having a surface substantially parallel to a c-axis of the YBCO; a ninth layer of NBCO formed on the surface of the eighth layer of YBCO, the ninth layer of NBCO having a surface substantially parallel to a c-axis of the NBCO; a ninth layer of YBCO formed on the surface of the ninth layer of NBCO, the ninth layer of YBCO having a surface substantially parallel to a c-axis of the YBCO; a tenth layer of NBCO formed on the surface of the ninth layer of YBCO, the tenth layer of NBCO having a surface substantially parallel to a c-axis of the NBCO; and a tenth layer of YBCO formed on the surface of the tenth layer of NBCO, the tenth layer of YBCO having a surface substantially parallel to a c-axis of the YBCO. In some implementations, the composition further comprises a layer of gold formed on the surface of the tenth layer of YBCO. In some implementations, the composition further comprises a layer of gold substantially encasing the composition.

Devices Formed of and/or Incorporating ELR Materials

[00240] Various devices, applications, components, apparatuses, and/or systems may employ the ELR materials described herein. These devices, applications, components, apparatuses and/or systems are now discussed in greater detail in the following Chapters.

Chapter 1 – Nanowires Formed of ELR Materials

[00241] This chapter of the description refers to Figures 1-36 and Figures 37-A through Figure 45B-A; accordingly all reference numbers included in this section refer to elements found in such figures.

[00242] In various implementations of the invention, ELR materials may be used to form various nanowires and nanowire components as will be described in further detail below. Accordingly, in some implementations of the invention, these ELR materials may be formed into various nanowire components so that current is primarily conducted along a b-axis of the ELR material. In these implementations, the ELR material may be formed with a length referenced to the b-axis, a width referenced to the c-axis, and a depth (or thickness) referenced to the a-axis as illustrated in Figure 39-A, although other reference frames, orientations and configurations may be used for ELR materials as will become apparent from this description. The reference frame depicted in Figure 39-A will be used for the following discussion.

[00243] In some implementations of the invention, various ELR materials may be used to form nanowires. In conventional terms, nanowires are nanostructures that have widths or diameters on the order of tens of nanometers or less and generally unstrained lengths. In some implementations of the invention, various modified ELR materials 1060 may be formed into nanowires having a width and/or a depth of 50 nanometers. In some implementations of the invention, various modified ELR materials 1060 may be formed into nanowires having a width and/or a depth of 40 nanometers. In some implementations of the invention, various modified ELR materials 1060 may be formed into nanowires having a width and/or a depth of 30 nanometers. In some implementations of the invention, various modified ELR materials 1060 may be formed into nanowires having a width and/or a depth of 20 nanometers. In some implementations of the invention, various modified ELR materials 1060 may be formed into nanowires having a width and/or a depth of 10 nanometers. In some implementations of the invention, various modified ELR materials 1060 may be formed into nanowires having a width and/or a depth of 5 nanometers. In some implementations of the invention, various modified ELR materials 1060 may be formed into nanowires having a width and/or a depth less than 5 nanometers. In some implementations of the invention, various new ELR materials designed as described above may be formed into nanowires having a width and/or a depth of 50 nanometers. In some implementations of the invention, various new ELR materials designed as described above may be formed

into nanowires having a width and/or a depth of 40 nanometers. In some implementations of the invention, new ELR materials designed as described above may be formed into nanowires having a width and/or a depth of 30 nanometers. In some implementations of the invention, various new ELR materials designed as described above may be formed into nanowires having a width and/or a depth of 20 nanometers. In some implementations of the invention, various new ELR materials designed as described above may be formed into nanowires having a width and/or a depth of 10 nanometers. In some implementations of the invention, various new ELR materials designed as described above may be formed into nanowires having a width and/or a depth of 5 nanometers. In some implementations of the invention, various new ELR materials designed as described above may be formed into nanowires having a width and/or a depth less than 5 nanometers.

[00244] In some implementations of the invention, nanowires may be stacked on top of one another with a buffer and/or substrate layer disposed in between to form layered nanowires. Each of the nanowires disposed in each layer may be formed from new ELR materials or modified ELR materials 1060 as discussed above and may have any of the widths and/or depths set forth above.

[00245] In some implementations of the invention, nanowires may be used to carry charge from a first end to a second end. Each of these ends may be connected to an electrical component including, but not limited to, another nanowire, a wire, a trace, a lead, an interconnect, an electronic device, an electronic circuit, a semiconductor device, a transistor, a memristor, a resistor, a capacitor, an inductor, a MEMs device, a pad, a voltage source, a current source, a ground, or other electrical component. In some implementations of the invention, nanowires may be coupled to may be coupled directly to one or more of these electrical components via the ELR material of the nanowire. In some implementations of the invention, nanowires may be coupled indirectly to these electrical components via another type of ELR material (i.e., modified versus unmodified ELR material, an ELR material in the same family or class of ELR materials, etc.). In some implementations of the invention, nanowires may be coupled indirectly to these electrical components via a conductive material, including but not limited to, a conductive metal.

[00246] Figure 37-A illustrates a cross-section of an exemplary ELR material 3700 parallel to the c-plane and through the centers of apertures 3710 formed in ELR material 3700 in accordance with various implementations of the invention. For purposes of the

following discussion and implementations of the invention, ELR material 3700 corresponds to conventional ELR materials (i.e., unmodified superconducting and/or HTS materials (e.g., unmodified YBCO, etc.)) as well as various modified ELR materials 1060 and new ELR materials, various implementations of which are described above. Figure 37-A illustrates various apertures 3710 through ELR material 3700 including a-axis apertures 3710A, b-axis apertures 3710B, and ab-axis apertures 3710C. A-axis apertures 3710A correspond to apertures 3710 through ELR material 3700 that are substantially parallel to the a-axis; b-axis apertures 3710B correspond to apertures 3710 through ELR material 3700 that are substantially parallel to the b-axis; ab-axis apertures 3710C correspond to apertures 3710 through ELR material 3700 that are substantially parallel to various axes in the c-plane offset from the a-axis (or the b-axis) by various angles, such as an angle 3720. As would be appreciated, not all apertures 3710 through ELR material 3700 are illustrated in Figure 37-A – many have not been illustrated for purposes of clarity and ease of illustration.

[00247] As would also be appreciated, apertures 3710 are dependent upon the crystalline structure of ELR material 3700. For example, as illustrated in Figure 37-A, ab-axis apertures 3710C of ELR material 3700 (which in this example corresponds to YBCO) exist at an angle of +/-45 degrees from the a-axis. By way of further example, Figure 38-A illustrates a b-axis aperture 3710B in ELR material 3700 relative to an ab-axis aperture 3710C in exemplary ELR material 3700. Other ab-axis apertures 3710C may exist in other ELR materials, including additional ab-axis apertures 3710C at other angles (e.g., +/-30 degrees, +/-60 degrees, etc.) as would be appreciated. Similarly, while a-axis apertures 3710A and b-axis apertures 3710B are illustrated in Figure 37-A as orthogonal to one another in ELR material 3700, other orientations of such apertures 3700 may exist depending on the crystalline structure of other ELR materials as would be appreciated.

[00248] Conventional superconducting materials, including HTS materials, exhibit various phenomenon typically associated with such superconducting materials. In addition to extremely low resistance, these superconducting materials exhibit the Meissner effect which manifests as an apparent absence or expulsion of electromagnetic fields from the interior of the superconducting materials as would be appreciated. The Meissner effect is believed to be the result of vortices, or loop currents, formed in the interior of the superconducting material. These vortices are believed to produce magnetic fields in the interior of the superconducting material that, in the aggregate, tend

to cancel one another out, thereby creating the apparent absence or expulsion of the electromagnetic fields in the interior. Controlling (or eliminating) these vortices may control (or eliminate) the Meissner effect exhibited by the superconducting material. In other words, controlling (or eliminating) these vortices may prevent the net cancellation of magnetic fields in the interior of the superconducting material.

[00249] Vortices are believed to be formed within ELR material 3700 when current "loops back" on itself within ELR material 3700. This is now described with reference to current path 3730 (illustrated in Figure 37-A as a current path 3730A, a current path 3730B, a current path 3730C, a current path 3730D, and a current path 3730E). As illustrated, as a current flows through ELR material 3700, the current may proceed along current path 3730A through an aperture 3710A. The current proceeds through aperture 3710A until reaching an intersection between various apertures 3710 in ELR material 3700, namely intersection 3740A.

[00250] At intersections 3740 generally, current is believed to be capable of deviating from its current "straightline" path in one aperture 3710 to another path through a different aperture 3710. For example, when reaching intersection 3740A, the current may continue along current path 3730A through aperture 3710A or deviate in some fashion from current path 3730A, such as along current path 3730B through aperture 3710B. As illustrated, the current has deviated by 45 degrees from its original path on current path 3730A to current path 3730B.

[00251] After current deviates from current path 3730A to current path 3730B, current proceeds along current path 3730B through aperture 3710C until reaching intersection 3740B. Again, the current may continue along current path 3730B through aperture 3710C or deviate in some fashion from current path 3730B, such as along current path 3730C through aperture 3710B. As illustrated, the current has deviated by a total of 90 degrees from its original path (by two 45-degree deviations). This process may continue as the current reaches other intersections, such as intersection 3740C and intersection 3740D. At intersection 3740C, the current may deviate from current path 3730C through aperture 3710B to current path 3730D through aperture 3710C, and at intersection 3740D, the current may deviate from current path 3730D through aperture 3710C to current path 3730E through aperture 3710A. As illustrated, at current path 3730E, the current has deviated by a total of 180 degrees from its original path (by four 45-degree deviations). While not otherwise illustrated, this process may continue until the current loops back on itself along current path 3730A as would be appreciated.

[00252] Figure 37-A illustrates that there may be a threshold depth of ELR material 3700 (which as illustrated in Figure 39-A, depth is referenced to the a-axis) necessary for current loops to form in ELR material 3700. More particularly, as illustrated in Figure 37-A, a depth of ELR material 3700 sufficient to include five adjacent apertures 3710B may be necessary for current loops to form in ELR material 3700. In other words, fewer than this number of apertures 3710B may not provide a sufficient number of deviations (or turns) and subsequent paths for current to loop back on itself within this threshold depth of ELR material 3700. If the depth of ELR material 3700 is less than this threshold depth, then loop currents may not form in ELR material 3700 thereby preventing the Meissner effect from occurring. Similarly, Figure 37-A illustrates that there may be a threshold length (which as illustrated in Figure 39-A, length is referenced to the b-axis) of ELR material 3700 necessary for current loops to form in ELR material 3700. More particularly, as extrapolated from Figure 37A, a length of ELR material 3700 sufficient to include five adjacent apertures 3710B may be necessary for current loops to form in ELR material 3700. If the length of ELR material 3700 is less than this threshold length, then loop currents may not form in ELR material 3700 thereby preventing the Meissner effect from occurring. These threshold depths and/or lengths may be different for other ELR materials with having crystalline structures other than that depicted in Figure 37-A, more or fewer apertures, apertures with different directions, apertures at different deviation angles, etc., as would be appreciated.

[00253] Furthermore, these threshold depths and/or lengths presume that current may deviate by a single turn at each intersection 3740. In other words, the current is presumed in the example illustrated to deviate only in increments of +/-45 degrees (as opposed to 90 degrees or more) at each intersection 3740. If larger incremental deviations may occur or if deviations occur at locations other than intersections 3740, then the threshold depth and/or threshold length of ELR material 3700 where the Meissner effect (or other superconducting phenomenon) does not occur may be less as would be appreciated. Similarly, if deviations may only occur at certain intersections 3740 (and not all intersections 3740), then the threshold depth and/or threshold length of ELR material 3700 where the Meissner effect (or other superconducting phenomenon) does not occur may be more as would be appreciated. Nonetheless, according to various implementations of the invention, ELR material 3700 has a threshold depth and/or a threshold length necessary to form loop currents.

[00254] According to various implementations of the invention, a nanowire may be formed using an ELR material, where the nanowire exhibits extremely low resistance but does not exhibit certain other superconductivity phenomenon (e.g., the Meissner effect) by controlling one or more dimensional parameters of the nanowire. For example, according to various implementations of the invention, a depth of the nanowire is selected to be less than the threshold depth of ELR material necessary for loop currents to form in the ELR material. According to various implementations of the invention, a length of the nanowire is selected to be less than the threshold length of ELR material necessary for loop currents to form in the ELR material. According to various implementations of the invention, the depth and the length of the nanowire may be less than those thresholds necessary for loop currents to form in the ELR material. These nanowires may then appear as perfect conductors along their depth and/or length without exhibiting other superconducting phenomenon. Stated differently, according to various implementations of the invention, nanowires have a threshold depth or a threshold length (and in some implementations and/or with some ELR materials, potentially a threshold width) within which the nanowires operate as perfect conductors and beyond which the nanowires operate as superconductors. While discussed above in terms of a threshold depth and/or a threshold length of ELR material 3700, it will be appreciated from Figure 37-A that in some instances loop currents may actually require a threshold area of ELR material 3700 to form.

[00255] For purposes of this description, these thresholds may be expressed in terms of a number of adjacent apertures 3710 along a given dimension, a number of unit crystals along a given dimension, or other number of unit measures associated with the crystalline structure of ELR material 3700 as would be appreciated. As would also be appreciated, these thresholds may be expressed in terms of units of measure (nanometers, Angstroms, etc.).

[00256] According to various implementations of the invention, nanowires that operate as perfect conductors may be formed of any length of ELR material 3700 provided that their depth does not exceed a threshold depth as discussed above. Likewise, according to various implementations of the invention, nanowires that operate as perfect conductors may be formed of any depth of ELR material 3700 provided that their length does not exceed a threshold length as discussed above. More particularly, according to various implementations of the invention, nanowires that operate as perfect conductors and that do not exhibit the Meissner effect may be formed of any length of ELR material

3700A provided that their depth does not exceed a threshold depth as discussed above. Likewise, according to various implementations of the invention, nanowires that operate as perfect conductors and that do not exhibit the Meissner effect may be formed of any depth of ELR material 3700 provided that their length does not exceed a threshold length as discussed above.

[00257] As would be appreciated, changing an orientation of the ELR material in Figure 39A would change the relevant threshold dimensions necessary for the Meissner effect to occur. For example, if the ELR material were oriented such that the a-axis and the c-axis were interchanged (i.e., the depth was referenced to the c-axis and the width was referenced to the a-axis), then width and/or length would be the dimensional parameters to control to avoid the Meissner effect as would be appreciated.

[00258] As mentioned above, nanowires may be formed from ELR material 3700, which may include conventional ELR materials (e.g., unmodified YBCO, etc.), modified ELR materials (e.g., ELR material 1060, chromium-modified YBCO, etc.), new ELR materials, or other ELR materials. Further, in some implementations of the invention, nanowires may be formed by depositing ELR material 3700 onto a substrate or buffer material as would be appreciated. In some implementations of the invention, nanowires may be formed by affixing ELR material 3700 onto a substrate such as a circuit board as would be appreciated.

[00259] In some implementations of the invention, such as those that utilize modified ELR materials (e.g., modified ELR material 1060), nanowires may be formed and operated above certain temperatures where only a portion of a modified ELR material 1060 has apertures 310 maintained at that certain temperature, and this portion of modified ELR material 1060 has a depth less that the threshold depth above which loop currents may be formed. For example, with reference to Figure 23, modified ELR material 1060 may be operated at a certain temperature where only apertures 310A and 310B are maintained. In this example, apertures 310A and 310B may not correspond to a sufficient depth of modified ELR material 1060 to form loop currents in modified ELR material 1060 and the Meissner effect may not occur.

[00260] According to various implementations of the invention, nanowires may be used to form various electrical components, including, but not limited to, a nanowire connector, a nanowire contour, a nanowire coil, and a nanowire converter. Figure 40-A illustrates examples of a nanowire connector 4000 according to various implementations of the invention. More particularly, Figure 40A-A illustrates a nanowire connector 4000A

formed from a nanowire including an ELR material oriented in a manner similar to that of Figure 39-A and described above, where the depth of the nanowire is less than the threshold depth necessary for loop currents to form in the ELR material. Figure 40B-A illustrates a nanowire connector 4000B formed from a nanowire including the ELR material oriented in a manner where the a-axis and the c-axis are interchanged from that of Figure 39-A, where the width of the nanowire is less than the threshold width necessary for loop currents to form in the ELR material. Other nanowire connectors 4000 may be formed from nanowires that include ELR materials in different orientations as would be appreciated. In some implementations of the invention, nanowire connector 4000 includes a nanowire that is a perfect conductor but that does not exhibit all the characteristics of a superconductor. In some implementations of the invention, nanowire connector 4000 includes a nanowire that is a perfect conductor that does not exhibit the Meissner effect. In some implementations of the invention, nanowire connector 4000 includes a nanowire that is formed from a conventional HTS material with a dimensional parameter controlled so that the nanowire operates as a perfect conductor but does not exhibit the Meissner effect. In some implementations of the invention, nanowire connector 4000 includes a nanowire that is formed from a modified ELR material 1060 with a dimensional parameter controlled so that the nanowire operates as a perfect conductor but does not exhibit the Meissner effect. In some implementations of the invention, nanowire connector 4000 includes a nanowire that is formed from a new ELR material with a dimensional parameter controlled so that the nanowire operates as a perfect conductor but does not exhibit the Meissner effect. As would be appreciated, nanowire connectors 4000 may be used to connect one electrical component to another electrical component (not otherwise illustrated).

[00261] Figure 41-A illustrates various single nanowire contours 4100 that may be formed from individual nanowires or nanowire segments according to various implementations of the invention. In some implementations of the invention, a nanowire contour 4100A includes three nanowire segments 4110, namely a nanowire segment 4110A, a nanowire segment 4110B, and a nanowire segment 4110C. In some implementations of the invention, a nanowire contour 4100B includes four nanowire segments 4110, namely a nanowire segment 4110A, a nanowire segment 4110B, a nanowire segment 4110C, and a nanowire segment 4110D. In some implementations of the invention, a nanowire contour 4100C includes five segments 4110, namely a nanowire segment 4110A, a nanowire segment 4110B, a nanowire segment 4110C, a

nanowire segment 4110D, and a nanowire segment 4110E. Nanowire contour 4100C differs from nanowire contour 4100B by the location of a pair of contour terminals. Other locations for contour terminals may be used in these or other nanowire contours 4100 as would be appreciated. In some implementations of the invention, a nanowire contour 4100D includes N nanowire segments 4110, namely a nanowire segment 4110A, a nanowire segment 4110B, a nanowire segment 4110C, & , and a nanowire segment 4110N. In some implementations of the invention, individual nanowire segments 4110 of nanowire contours 4100 may be coupled directly to one another via the ELR material of the nanowire. In some implementations of the invention, individual nanowire segments 4110 may be coupled indirectly to one another via a conductive material, including but not limited to, a conductive metal. Leads to nanowire contour 4100 (not otherwise illustrated) may or may not be formed from nanowires. Nanowire contours 4100 may be used for a variety of applications as would be appreciated and may be formed in a variety of shapes and sizes depending upon, for example, such applications. For example, nanowire contour 4100 may be used to form a so-called "current loop," which has various applications involving sensing and/or generating electric fields as would be appreciated.

[00262] Figure 42-A illustrates an exemplary nanowire coil 4200 that may be formed from one or more individual nanowire contours 4100 according to various implementations of the invention. Individual nanowire contours 4100 may be separated from one another by a substrate or buffer material and coupled to one another by, for example, a coupler 4210. As illustrated, nanowire coil 4200 is formed from a nanowire contour 4100V, a nanowire contour 4100W, a nanowire contour 4100X, a nanowire contour 4100Y, and a nanowire contour 4100Z. While illustrated in Figure 42-A as including five nanowire contours 4100, nanowire coil 4200 may include any number of nanowire contours 4100 as would be appreciated. As also illustrated in Figure 42-A, nanowire coil 4200 is configured to conduct current through each nanowire contour 4100 in the same general direction (e.g., clockwise or counter-clockwise). Nanowire coil 4200 may be used for a variety of applications as would be appreciated and may be formed in a variety of shapes and sizes depending upon, for example, such applications.

[00263] Figure 43-A illustrates a differential nanowire coil 4300 that may be formed from one or more pairs of nanowire contours 4100 according to various implementations of the invention. As illustrated in Figure 43-A, nanowire coil 4300 is formed from two pairs of a nanowire contours: a first pair including a nanowire contour 4100P and a nanowire

contour 4100Q; and a second pair including a nanowire contour 4100R and a nanowire contour 4100S. While illustrated in Figure 43-A as including two pairs of nanowire contours 4100, any number of pairs may be used in various implementations of the invention. Furthermore, in some implementations of the invention, nanowire coil 4300 may include a single nanowire contour 4100 in addition to one or more pairs of nanowire contours 4100 as would be appreciated. Nanowire contours 4100 in each pair of nanowire contours 4100 are coupled to one another (by, for example, coupler 4210) such that they conduct current in a different direction from one another. For example, as illustrated in Figure 43-A, nanowire contour 4100P conducts current in a direction different from that of nanowire contour 4100Q (i.e., one may conduct current clockwise while the other conducts current counter-clockwise). The same is true for nanowire contour 4100R and nanowire contour 4100S. Nanowire coil 4300 may be used for a variety of applications as would be appreciated and may be formed in a variety of shapes and sizes depending upon, for example, such applications.

[00264] Figure 44-A illustrates a nanowire coil 4400 that may be formed from one or more concentric nanowire contours 4100 according to various implementations of the invention. As illustrated in Figure 44-A, nanowire coil 4400 is formed from five nanowire contours 4100, including a nanowire contour 4100J, a nanowire contour 4100K, a nanowire contour 4100-L, a nanowire contour 4100M, and a nanowire contour N. While illustrated in Figure 44-A as including five nanowire contours 4100, any number of nanowire contours 4100 may be used in various implementations of the invention. As illustrated in Figure 44-A, nanowire contours 4100 are concentric with one another and successive nanowire contours 4100 reduce in size. For example, nanowire contour 4100K fits within and is smaller than nanowire contour 4100J. Likewise, nanowire contour 4100L fits within and is smaller than nanowire contour 4100K; nanowire contour 4100M fits within and is smaller than nanowire contour 4100-L; and nanowire contour 4100N fits within and is smaller than nanowire contour 4100M. As illustrated in Figure 44-A, nanowire contours 4100 are coupled to one another to form, for example a "spiral" nanowire coil 4400. Nanowire coil 4400 may be used for a variety of applications as would be appreciated and may be formed in a variety of shapes and sizes. Whereas nanowire coil 4200 and nanowire coil 4300 may be considered as being three-dimensional in nature (i.e., nanowire contours 4100 in each are "stacked" on one another), nanowire coil 4400 may be considered as being two-dimensional in nature (i.e., no stacking of nanowire contours 4100).

[00265] Figures 45A-A and 45B-A illustrate various nanowire converters 4500, according to various implementations of the invention, that may be used to convert energy from one form of energy to another form of energy. For example, a nanowire converter 4500A including at least two nanowire segments 4110 configured as a dipole may be used to convert electromagnetic radiation to an alternating voltage (e.g., V_{rms}) appearing across its terminals. In this mode, nanowire converter 4500A may be considered as a receiver (i.e., receiving or otherwise responsive to electromagnetic radiation). Conversely, nanowire converter 4500A may be used to convert an alternating voltage appearing across its terminals to electromagnetic radiation. In this mode, nanowire converter 4500A may be considered as a transmitter (i.e., transmitting or otherwise propagating electromagnetic radiation).

[00266] By way of another example, a nanowire converter 4500B including a nanowire contour 4100 (and which may also be considered a nanowire coil 4100) may be used to sense a changing current being carried by in a conductor 4510. More particularly, the current carried by conductor 4510 generates an electromagnetic field which in turn produces a current through terminals of nanowire converter 4500B according to well-known principles of physics. Conversely, a changing current applied to terminals of nanowire converter 4500B may be used to induce a current in conductor 4510. The changing current through the terminals of nanowire converter 4500B induces an electromagnetic field which in turn induces a current in conductor 4510.

[00267] By way of still further example, a nanowire converter 4500C including a nanowire coil 4200 may be used to sense a changing current being carried by in a conductor 4510. More particularly, the current carried by conductor 4510 generates an electromagnetic field which in turn produces a current through terminals of nanowire converter 4500C according to well-known principles of physics. Conversely, a changing current applied to terminals of nanowire converter 4500C may be used to induce a current in conductor 4510. Again, the changing current through the terminals of nanowire converter 4500C induces an electromagnetic field within the loops of nanowire converter 4500C which in turn induces a current in conductor 4510.

[00268] By way of yet still further example, a nanowire converter 4500D including a nanowire coil 4400 may be used to sense a changing current being carried by in a conductor 4510. More particularly, the current carried by conductor 4510 generates an electromagnetic field which in turn produces a current through terminals of nanowire converter 4500D according to well-known principles of physics. Conversely, a changing

current applied to terminals of nanowire converter 4500D may be used to induce a current in conductor 4510. Again, the changing current through the terminals of nanowire converter 4500D induces an electromagnetic field within the loops of nanowire converter 4500C which in turn induces a current in conductor 4510.

[00269] As would be appreciated, conductor 4510 is not necessary in various implementations of the invention discussed above with reference to Figure 45-A. In fact, any changing electromagnetic field present within the "loop(s)" of nanowire converter 4500, whether from conductor 4510 or otherwise, produces a current through the terminals of nanowire converter 4500. Likewise, a changing current through the terminals of nanowire converter 4500 produces an electromagnetic field within the loops of nanowire converter 4500. As would also be appreciated, the "changing electromagnetic field" referred to above may occur as a result of the field within the loop(s) of nanowire converter 4500 changing, the position of nanowire converter 4500 changing relative to the field, the position of nanowire converter 4500 changing relative to conductor 4510, and/or a change in the current being carried by conductor 4510 as would also be appreciated.

[00270] In some implementations, a nanowire that includes modified ELR materials may be described as follows:

[00271] A nanowire comprising a modified ELR material.

[00272] A nanowire comprising a plurality of layers of modified ELR material, each of the plurality of layers of ELR material separated from another of the plurality of layers by a buffer or substrate material.

[00273] An electrical system comprising: a first nanowire comprising a modified ELR material; and a second nanowire comprising a non-ELR material, wherein the first nanowire is electrically coupled to the second nanowire.

[00274] An ELR nanowire comprising: an ELR material having three dimensional parameters, including a length, a width, and depth, wherein at least one of the dimensional parameters is less than a threshold such that the ELR nanowire does not exhibit at least one superconducting phenomenon while operating with extremely low resistance.

[00275] An ELR nanowire comprising: an ELR material having three dimensional parameters, including a length, a width, and depth; and a modifying material disposed on an appropriate surface of the ELR material, wherein at least one of the dimensional

parameters is less than a threshold such that the ELR nanowire does not exhibit at least one superconducting phenomenon while operating with extremely low resistance.

[00276] An ELR nanowire contour comprising: at least one ELR nanowire segment, each ELR nanowire segment comprising: an ELR material having three dimensional parameters, including a length, a width, and depth, wherein at least one of the dimensional parameters is less than a threshold such that the ELR nanowire segment does not exhibit at least one superconducting phenomenon while operating with extremely low resistance.

[00277] An ELR nanowire contour comprising: a plurality of ELR nanowire segments, each of the plurality of ELR nanowire segments comprising an ELR material having three dimensional parameters, including a length, a width, and depth, a modifying material disposed on an appropriate surface of the ELR material, wherein at least one of the dimensional parameters is less than a threshold such that the ELR nanowire segment does not exhibit at least one superconducting phenomenon while operating with extremely low resistance.

[00278] An ELR nanowire coil comprising: at least one ELR nanowire contour, each of the at least one ELR nanowire contour comprising a plurality of ELR nanowire segments, each of the plurality of ELR nanowire segments coupled to at least one other of the plurality of ELR nanowire segments to substantially form a polygon, each of the at least one ELR nanowire segments comprising: an ELR material having three dimensional parameters, including a length, a width, and depth, wherein at least one of the dimensional parameters is less than a threshold such that the ELR nanowire segment does not exhibit at least one superconducting phenomenon while operating with extremely low resistance.

[00279] An ELR nanowire coil comprising: a plurality of ELR nanowire contours, each of the plurality of ELR nanowire contours comprising a plurality of ELR nanowire segments, each of the plurality of ELR nanowire segments coupled to at least one other of the plurality of ELR nanowire segments to substantially form a polygon, each of the plurality of ELR nanowire segments comprising: an ELR material having three dimensional parameters, including a length, a width, and depth, a modifying material disposed on an appropriate surface of the ELR material, wherein at least one of the dimensional parameters is less than a threshold such that the ELR nanowire segment does not exhibit at least one superconducting phenomenon while operating with extremely low resistance.

[00280] A nanowire converter comprising: at least one nanowire segment, wherein the nanowire converter either senses an electromagnetic field or induces an electromagnetic field.

[00281] A nanowire converter comprising: at least one nanowire segment disposed within an electromagnetic field, wherein the nanowire converter senses the electromagnetic fields and converts it to an alternating voltage.

[00282] A nanowire converter comprising: at least one nanowire segment electrically couples to an alternating voltage source, wherein the nanowire converter induces an electromagnetic field in response to the alternating voltage source.

Chapter 2 – Josephson Junctions Formed of ELR Materials

[00283] This chapter of the description refers to Figures 1-36 and Figures 37-A through Figure 46J; accordingly all reference numbers included in this section refer to elements found in such figures.

[00284] Figures 46A-A to 46H-A illustrate various Josephson junctions 4600 (illustrated in the figures as a Josephson junction 4600A in Figure 46A-A, a Josephson junction 4600B in Figure 46B-A, a Josephson junction 4600C in Figure 46C-A, a Josephson junction 4600D in Figure 46D-A, a Josephson junction 4600E in Figure 46E-A, a Josephson junction 4600F in Figure 46F-A, a Josephson junction 4600G in Figure 46G-A, and a Josephson junction 4600H in Figure 46H-A) according to one or more implementations of the invention. Figure 46A-A illustrates Josephson junction 4600A, which includes two ELR conductors 4620 separated by a barrier 4610. In some implementations of the invention, each ELR conductor 4620 comprises ELR materials that operate with improved operational characteristics in accordance with various implementations of the invention. For example, in some implementations of the invention, each ELR conductor 4620 comprises modified ELR material 1060; and in some implementations of the invention, each ELR conductor 4620 comprise new ELR materials with improved operating characteristics. In some implementations of the invention, each ELR conductor 4620 comprises a nanowire segment 4110 in accordance with various implementations of the invention.

[00285] In some implementations of the invention, barrier 4610 comprises an insulating material disposed between and electrically coupled to ELR conductors 4620 In these implementations, barrier 4610 is very thin, typically 30 angstroms or less, as would be appreciated. In some implementations of the invention, barrier 4610 comprises a conductive material, such as a conductive metal, disposed between ELR conductors

4620. In some implementations of the invention, barrier 4610 comprises a conductive material, such as a ferromagnetic metal, disposed between ELR conductors 4620. In these implementations, barrier 4610 may be thicker than with insulating materials, typically several microns thick, as would be appreciated. In some implementations of the invention, barrier 4610 comprises a semi-conductive material, such as a conductive metal, disposed between ELR conductors 4620. In some implementations of the invention, barrier 4610 comprises other materials, such as but not limited to, a different ELR material from that of ELR conductors 4620 (i.e., different in the sense that it may have a different chemical composition, a different crystalline structure, a different crystalline structure orientation, a different phase, a different grain boundary, a different critical current, a different critical temperature, or other difference). In some implementations of the invention, barrier 4610 comprises the same ELR material as that of ELR conductors 4620, but different in the sense of one or more mechanical aspects (i.e., a different thickness of ELR material from that of ELR conductors 4620, a different width of ELR material from that of ELR conductors 4620, or other mechanical difference). In some implementations, barrier 4610 comprises a partial or complete gap formed between ELR conductors 4620. In these implementations, barrier 4610 may comprise a gap filled with air or other gas. In some implementations of the invention where ELR conductors 4620 comprise modified ELR material 1020, barrier 4610 may comprise unmodified ELR material 360.

[00286] Common types of conventional Josephson junctions include: superconductor-insulator-superconductor ("SIS"); superconductor-normal conductor-superconductor ("SNS"); superconductor-ferromagnetic metal-superconductor ("SFS"); superconductor-insulator-normal conductor-insulator-superconductor ("SINIS"); superconductor-insulator-normal conductor-superconductor ("SINS"); superconductor-constriction-superconductor ("SCS"); and others. Figure 46I-A illustrates various examples of these Josephson junctions, including, but not limited to (from left to right, top down): a tunnel junction (SIS); a point contact; a Daydem bridge (SCS); a sandwich junction; a variable thickness bridge; and an ion-implanted bridge. Figure 46J-A illustrates various other examples of Josephson junctions, including but not limited to (from left to right, top down): a step-edge SNS junction; a step-edge grain boundary junction; a ramp edge junction; and a bi-crystal grain boundary junction. According to various implementations of the invention, any of these aforementioned types of Josephson junctions may be configured

using improved ELR materials, such as those discussed above, in place of the superconducting material of conventional Josephson junctions.

[00287] Generally speaking, Josephson junctions 4600 exhibit a so-called Josephson effect where current flowing in an ELR state through ELR conductors 4620 is also able to flow across a junction between ELR conductors 4620 in an extremely low resistance state, where the junction may comprise, for example, a barrier 4610. The current that flows through barrier 4610 is referred to as a Josephson current. Up until it reaches a critical current, the Josephson current is able to flow through barrier 4610 with extremely low resistance. However, when the critical current of barrier 4610 is exceeded, a voltage appears across barrier 4610 which in turn further reduces the critical current thereby producing a larger voltage across barrier 4610. The Josephson effect may be exploited with Josephson junctions 4600 in various circuits as would be appreciated.

[00288] Figure 46A-A illustrates various implementations of Josephson junctions 4600A in a "wire configuration," and include, but are not limited to, bulk material conductors, wires, nanowires, traces, and other configurations as would be appreciated.

[00289] Figure 46B-A illustrates a Josephson junction 4600B in a "foil configuration" or "plate configuration," and include, but are not limited to, bulk material plates, foils, or other layered configurations as would be appreciated in accordance with various implementations of the invention. Josephson junction 4600B may be used, for example, to detect photons incident on one of ELR conductors 4620. Other uses for Josephson junction 4600B exist as would be appreciated.

[00290] Figure 46C-A and Figure 46D-A illustrate Josephson junctions 4600 in the so-call "wire configuration." Figure 46C-A illustrates a Josephson junction 4600C that comprises ELR conductors 4620 that include a modified ELR material that has improved operating characteristics in accordance with various implementations of the invention. As illustrated in Figure 46C-A, in some implementations of the invention, each ELR conductor 4620 of Josephson junction 4600C includes a modified ELR material comprising modifying material 2720 layered onto an ELR material 3110. In some implementation of the invention, the modified ELR material may be layered onto substrate 2420 (i.e., ELR material is layered onto substrate 2420). ELR conductors 4620 may comprise other forms of modified ELR material as would be appreciated. As illustrated, barrier 4610 is disposed between and electrically coupled to ELR conductors 4620.

[00291] Figure 46D-A illustrates a Josephson junction 4600D that comprises ELR conductors 4620 that include a modified ELR material that has improved operating characteristics in accordance with various implementations of the invention. As illustrated in Figure 46D-A, in some implementations of the invention, each ELR conductor 4620 of Josephson junction 4600D includes a modified ELR material comprising modifying material 2720 layered onto an ELR material 3110. In some implementation of the invention, the modified ELR material may be layered onto substrate 2420 (i.e., ELR material is layered onto substrate 2420). ELR conductors 4620 may comprise other forms of modified ELR material as would be appreciated. As illustrated, barrier 4610 is disposed between and electrically coupled to ELR conductors 4620, and more particularly barrier 4610 is disposed between the layers of ELR material 3110, and under a continuous layer of modifying material 2720. Josephson junction 4600D may be desirable, for example, from a manufacturing standpoint over Josephson junction 4600C as would be appreciated. In some implementations of the invention, such as, but not limited to, those illustrated in Figure 46C-A and Figure 46D-A, barrier 4610, may comprise modifying material 2720.

[00292] Figure 46E-A illustrates a Josephson junction 4600E that comprises ELR conductors 4620 that include a modified ELR material that has improved operating characteristics in accordance with various implementations of the invention. As illustrated in Figure 46E-A, in some implementations of the invention, each ELR conductor 4620 of Josephson junction 4600E includes a modified ELR material comprising modifying material 2720 layered onto an ELR material 3110. As illustrated in Figure 46E-A, barrier 4610 is formed by a break (e.g., a gap) in a layer of modifying material 2720 over a continuous layer of ELR material 3110. Such a gap in the layer of modifying material 2720 may be formed by a variety of processing techniques including etching, milling, shadowmask, or other processing techniques as would be appreciated. Josephson junction 4600E is formed then from two ELR conductors 4620 comprising the modified ELR material (e.g., a layer of modifying material 2720 over a layer of ELR material 3110) separated by a barrier 4610 comprising a layer of ELR material 3110 without modifying material 2720 (i.e., a layer of unmodified ELR material 3110). Josephson junction 4600E may be desirable, for example, from a manufacturing standpoint over other Josephson junctions as would be appreciated.

[00293] Figure 46F-A illustrates a Josephson junction 4600F that comprises ELR conductors 4620 that include a modified ELR material that has improved operating

characteristics in accordance with various implementations of the invention. As illustrated in Figure 46F-A, in some implementations of the invention, each ELR conductor 4620 of Josephson junction 4600F includes a modified ELR material comprising modifying material 2720 layered onto an ELR material 3110. As with Josephson junction 4600E, barrier 4610 of Josephson junction 4600F is formed by a gap in the layer of modifying material 2720 over the continuous layer of ELR material 3110. As a result, Josephson junction 4600F is also formed from two ELR conductors 4620 comprising the modified ELR material separated by a barrier 4610 comprising the unmodified ELR material 3110. In some implementations of the invention, a layer of insulating or buffer material 4630 may be layered over modifying material 2720, and as illustrated in Figure 46F-A, such material 4630 may fill the gap in the layer of modifying material 2720, thereby providing a further aspect to barrier 4610.

[00294] Figure 46G-A illustrates a Josephson junction 4600G that comprises ELR conductors 4620 that include a modified ELR material that has improved operating characteristics in accordance with various implementations of the invention. As illustrated in Figure 46G-A, in some implementations of the invention, each ELR conductor 4620 of Josephson junction 4600G includes a modified ELR material comprising modifying material 2720 layered onto an ELR material 3110. As with Josephson junctions 4600E and 4600F, barrier 4610 of Josephson junction 4600G is formed by a gap in the layer of modifying material 2720 over a layer of ELR material 3110. In addition, barrier 4610 of Josephson junction 4600G also includes a partial gap (i.e., a mechanical constriction in depth or thickness) in the layer of ELR material 3110. For example, the processing techniques used to create the gap in the layer of modifying material 2720 may, intentionally or unintentionally, create the partial gap in the underlying layer of ELR material 3110. As a result, Josephson junction 4600G is formed from two ELR conductors 4620 comprising the modified ELR material separated by a barrier 4610 comprising the unmodified ELR material 3110 with a further mechanical constriction. In some implementations of the invention, a layer of insulating or buffer material 4630 may be layered over modifying material 2720, and as illustrated in Figure 46G-A, such material 4630 may fill the gap in the layer of modifying material 2720 as well as the partial gap in the layer of ELR material 3110, thereby providing a further aspect to barrier 4610.

[00295] Figure 46H-A illustrates a Josephson junction 4600H that comprises ELR conductors 4620 that include a modified ELR material that has improved operating

characteristics in accordance with various implementations of the invention. As illustrated in Figure 46H-A, in some implementations of the invention, each ELR conductor 4620 of Josephson junction 4600H includes a modified ELR material comprising modifying material 2720 layered onto an ELR material 3110. As above, barrier 4610 of Josephson junction 4600H is formed by a gap in both the layer of modifying material 2720 and the layer of ELR material 3110. As a result, Josephson junction 4600H is formed from two ELR conductors 4620 comprising the modified ELR material separated by the gap. In some implementations of the invention, a layer of insulating or buffer material 4630A may be layered over modifying material 2720, and as illustrated in Figure 46H-A, such material 4630 may fill the gap in both the layer of modifying material 2720 and the layer of ELR material 3110.

[00296] In some implementations of the invention, a plurality of Josephson junctions 4600 may be organized in a one-dimensional array of serially-coupled Josephson junctions 4600 as would be appreciated. In some implementations of the invention, a plurality of Josephson junctions 4600 may be organized in a two-dimensional array of Josephson junctions including a plurality of one-dimensional arrays of serially-coupled Josephson junctions 4600 coupled in parallel with one another as would be appreciated.

[00297] In some implementations, a Josephson Junction that includes modified ELR materials may be described as follows:

[00298] A Josephson junction comprising: a first ELR conductor comprising an ELR material having improved operating characteristics; a second ELR conductor comprising the ELR material; and a barrier material disposed between the first ELR conductor and the second ELR conductor.

[00299] A Josephson junction comprising: a first ELR conductor comprising an ELR material having a critical temperature greater than 150K; a second ELR conductor comprising the ELR material; and a barrier material disposed between the first ELR conductor and the second ELR conductor.

[00300] A circuit comprising: a plurality of Josephson junctions, wherein each of the plurality of Joseph junctions comprises: a first ELR conductor comprising an ELR material having a critical temperature greater than 150K, a second ELR conductor comprising the ELR material, and a barrier material disposed between the first ELR conductor and the second ELR conductor.

[00301] A Josephson junction comprising: a first ELR conductor comprising a modified ELR material; a second ELR conductor comprising the modified ELR material; and a

barrier material disposed between the first ELR conductor and the second ELR conductor, wherein the modified ELR material comprises a first layer of ELR material and a second layer of modifying material bonded to the ELR material of the first layer, where the modified ELR material has improved operating characteristics over those of the ELR material alone.

[00302] A Josephson junction comprising: a first ELR conductor comprising a modified ELR material; a second ELR conductor comprising the modified ELR material; and a barrier material disposed between the first ELR conductor and the second ELR conductor, wherein the modified ELR material comprises a first layer of ELR material and a second layer of modifying material bonded to the ELR material of the first layer, where the modified ELR material has a critical temperature greater than 150K.

[00303] A circuit comprising a plurality of Josephson junctions, wherein each of the plurality of Joseph junctions comprises a first ELR conductor comprising a modified ELR material; a second ELR conductor comprising the modified ELR material; and a barrier material disposed between the first ELR conductor and the second ELR conductor, wherein the modified ELR material comprises a first layer of ELR material and a second layer of modifying material bonded to the ELR material of the first layer, where the modified ELR material has a critical temperature greater than 150K.

[00304] A Josephson junction comprising: a first layer of ELR material; and a second layer of modifying material bonded onto the first layer of ELR material, the second layer having a first portion and a second portion with a gap formed between the first portion and the second portion and over the first layer of ELR material, wherein the first portion of the second layer of modifying materials bonded to the first layer of ELR material forms a first portion of a modified ELR material, wherein the second portion of the second layer of modifying materials bonded to the first layer of ELR material forms a second portion of the modified ELR material, and wherein the gap in the second layer of modifying material provides an unmodified portion of ELR material, wherein the unmodified portion of ELR material forms a barrier of the Josephson junction, wherein the modified ELR material has improved operating characteristics over those of the ELR material alone.

[00305] A Josephson junction comprising: a first layer of ELR material; and a second layer of modifying material bonded onto the first layer of ELR material, the second layer having a first portion and a second portion with a gap formed between the first portion and the second portion and over the first layer of ELR material, wherein the first portion of the second layer of modifying materials bonded to the first layer of ELR material forms

a first portion of a modified ELR material, wherein the second portion of the second layer of modifying materials bonded to the first layer of ELR material forms a second portion of the modified ELR material, and wherein the gap in the second layer of modifying material provides an unmodified portion of ELR material, wherein the unmodified portion of ELR material forms a barrier of the Josephson junction, wherein the modified ELR material operates in an ELR state at temperatures greater than 150K.

[00306] A circuit comprising: a first layer of ELR material; and a second layer of modifying material bonded onto the first layer of ELR material, the second layer having a plurality of portions of modifying material with a gap formed between each pair of adjacent ones of the plurality of portions of modifying material, wherein each of the plurality of portions of modifying material is bonded to the first layer of ELR material to form a portion of a modified ELR material, and wherein the gap formed between each pair of adjacent ones of the plurality of portions of modifying material provides an unmodified portion of ELR material, wherein the unmodified portion of ELR material forms a barrier of a Josephson junction, wherein the modified ELR material operates in an ELR state at temperatures greater than 150K.

[00307] A Josephson junction comprising: a first ELR wire comprising an ELR material having a critical temperature greater than 150K; a second ELR wire comprising the ELR material; and a barrier material disposed between the first ELR wire and the second ELR wire.

[00308] A Josephson junction comprising: a first ELR foil comprising an ELR material having a critical temperature greater than 150K; a second ELR foil comprising the ELR material; and a barrier material disposed between the first ELR foil and the second ELR foil.

Chapter 3 – QUIDS Formed of ELR Materials

[00309] This chapter of the description refers to Figures 1-36 and Figures 37-A through Figure 53-A; accordingly all reference numbers included in this section refer to elements found in such figures.

[00310] Figure 47-A illustrates an ELR QUID 4700 (i.e., ELR quantum interference device) that includes an ELR loop 4710 with a single ELR Josephson junction 4600 according to various implementations of the invention. More particularly, ELR loop 4710 includes an ELR conductor 4620 formed in a loop with a single barrier 4610 disposed within a leg of loop to form ELR Josephson junction 4600. ELR QUID 4700 generally operates in a manner similar to other quantum interference devices, including

superconducting quantum interference devices or "SQUIDs" The operation and use of SQUIDs are generally well known. As would be appreciated, ELR QUID 4700 may sometimes be referred to as a "single-junction QUID, a "one-junction QUID," or "RF QUID." ELR QUID 4700 is formed from ELR materials that operate with improved operational characteristics in accordance with various implementations of the invention. For example, in some implementations of the invention, ELR QUID 4700A comprises modified ELR material 1060; in some implementations of the invention, ELR QUID 4700 comprises apertured ELR material with improved operational characteristics; and in some implementations of the invention, ELR QUID 4700 comprises new ELR materials in accordance with various implementations of the invention.

[00311] Generally, speaking ELR QUID 4700 may be used to detect magnetic fields that flow through ELR loop 4710 (i.e., perpendicular to and through the interior area formed by ELR loop 4710) as would be appreciated. More particularly, ELR QUID 4700 may be coupled to a RF generator that induces a current in ELR loop 4710. Such an RF generator, sometimes also referred to as an AC biasing circuit 5000, is illustrated in Figure 50-A. AC biasing circuit 5000 utilizes an AC current 5020 through an inductor 5010 to generate an RF field that, in turn, induces a current in ELR loop 4710 of ELR QUID 4700. In various implementations of the invention, the current in ELR loop 4710 (which may be controlled via current 5020 through inductor 5010) is kept at or just below the critical current of barrier 4610 of Josephson junction 4600 in ELR QUID 4700. A magnetic field flowing through the interior area of ELR loop 4710 causes the current in ELR loop 4710 to exceed the critical current of barrier 4610, thereby producing a voltage across barrier 4610 which can be detected and/or measured as would be appreciated.

[00312] Figure 48A-A illustrates a dual-feed ELR QUID 4800 generally, and more particularly a dual-feed ELR QUID 4800A. ELR QUID 4800A includes an ELR loop 4710 with a single ELR Josephson junction 4600 and two feeds 4810 (sometimes referred to as an input feed 4810A and an output feed 4810 depending on the flow of current through ELR QUID 4800A) according to various implementations of the invention. Feeds 4810 are symmetrically placed in ELR loop 4710 to ensure that the current through each leg of ELR loop 4710 are equal. As such, ELR loop 4710 is sometimes referred to as a symmetrical ELR loop.

[00313] ELR loop 4710 of ELR QUID 4800A includes an ELR conductor 4620 formed in a loop with a single barrier 4610 disposed within a leg of loop to form ELR Josephson junction 4600. ELR QUIDs 4800 may be formed from ELR materials that operate with

improved operational characteristics in accordance with various implementations of the invention. For example, in some implementations of the invention, ELR QUID 4800 comprises modified ELR material 1060; in some implementations of the invention, ELR QUID 4800 comprises apertured ELR material with improved operational characteristics; and in some implementations of the invention, ELR QUID 4800 comprises new ELR materials in accordance with various implementations of the invention.

[00314] Figure 48B-A illustrates a dual-feed ELR QUID 4800B according to various implementations of the invention. ELR QUID 4800B differs from ELR QUID 4800A in that feeds 4810 are offset from a center axis of ELR loop 4710 such that feeds 4810 are disposed closer to a leg 4830 (which includes barrier 4610) of ELR loop 4710 and farther from a leg 4820 of ELR loop 4710. As thus described, feeds 4810 are asymmetrically placed in ELR loop 4710. While not otherwise illustrated, in various implementations of the invention, feeds 4810 may be offset from a center axis of ELR loop 4710 such that feeds 4810 are disposed closer to leg 4820 and farther from leg 4830. Similarly, in various implementations of the invention (not otherwise illustrated), one feed may be disposed closer to leg 4820 while the other feed may be disposed closer to leg 4830. The location of feeds 4810 in ELR loop 4710 may change a respective flow of current through each of legs 4820, 4830, and hence change an overall operation and/or sensitivity of ELR QUID 4800B as would be appreciated. As such, ELR loop 4710 of ELR QUID 4800B is sometimes referred to as an asymmetrical ELR loop.

[00315] Figure 48C illustrates a dual-feed ELR QUID 4800C according to various implementations of the invention. ELR QUID 4800C differs from ELR QUID 4800A in that a leg 4840 may be wider than a leg 4850 (which includes barrier 4610) of ELR loop 4710. As thus described, legs 4840, 4850 represent another asymmetry that may be utilized in ELR loop 4710. While not otherwise illustrated, in various implementations of the invention, leg 4850 may be wider than leg 4840. The widths of legs 4840, 4850 in ELR loop 4710 may change a respective flow of current through each of legs 4840, 4850, and hence change an overall operation and/or sensitivity of ELR QUID 4800C as would be appreciated. As such, ELR loop 4710 of ELR QUID 4800C is also sometimes referred to as an asymmetrical ELR loop.

[00316] Generally, speaking ELR QUID 4800 may be used as rapid single quantum flux ("RSQF") logic that may be used to generate a single pulse when a flux state of ELR QUID 4800A changes. In other words, ELR QUID 4800 generates a single pulse when a

field through the interior area formed by ELR loop 4710 changes. The pulse generated by ELR QUID 4800 typically has a relatively short pulse width as would be appreciated.

[00317] Figure 49A-A illustrates a dual-feed, two Josephson junctions ELR QUID 4900 generally, and more particularly a dual-feed, two Josephson junction ELR QUID 4900A. ELR QUID 4900A includes an ELR loop 4710 with two ELR Josephson junctions 4600 and two feeds 4810 according to various implementations of the invention. As illustrated, ELR QUID 4900 includes a symmetrical loop 4710. ELR loop 4710 of ELR QUID 4900A includes an ELR conductor 4620 formed in a loop with two barriers 4610, each disposed within a leg of loop to form ELR Josephson junction 4600. ELR QUIDs 4900 may be formed from ELR materials that operate with improved operational characteristics in accordance with various implementations of the invention. For example, in some implementations of the invention, ELR QUID 4900 comprises modified ELR material 1060; in some implementations of the invention, ELR QUID 4900 comprises apertured ELR material with improved operational characteristics; and in some implementations of the invention, ELR QUID 4900A comprises new ELR materials in accordance with various implementations of the invention.

[00318] Figure 49B-A illustrates a dual-feed, two Josephson junction ELR QUID 4900B according to various implementations of the invention. ELR QUID 4900B includes an asymmetrical ELR loop 4710 in that feeds 4810 are offset from a center axis of ELR loop 4710 as discussed above with reference to Figure 48B-A. While not otherwise illustrated, in various implementations of the invention, feeds 4810 may be offset from a center axis of ELR loop 4710 such that feeds 4810 are disposed closer to leg 4820 and farther from leg 4830. Similarly, in various implementations of the invention (not otherwise illustrated), one feed may be disposed closer to leg 4820 while the other feed may be disposed closer to leg 4830. The location of feeds 4810 in ELR loop 4710 may change a respective flow of current through each of legs 4820, 4830, and hence change an overall operation and/or sensitivity of ELR QUID 4900B as would be appreciated.

[00319] Figure 49C-A illustrates a dual-feed, two Josephson junction ELR QUID 4900C according to various implementations of the invention. ELR QUID 4900C includes an asymmetrical ELR loop 4710 in that legs 4840, 4850 are sized differently from one another as discussed above with reference to Figure 48C-A. While not otherwise illustrated, in various implementations of the invention, leg 4850 may be wider than leg 4840. The widths of legs 4840, 4850 in ELR loop 4710 may change a respective flow of

current through each of legs 4840, 4850, and hence change an overall operation and/or sensitivity of ELR QUID 4900C as would be appreciated.

[00320] While ELR QUIDs 4900A in Figures 49A-A to 49C-A are illustrated as having two Josephson junctions 4600, ELR QUIDs 4900A may comprise three or more Josephson junctions 4600 as would be appreciated. Generally speaking, such ELR QUIDs 4900 may be considered as parallel arrays of Josephson junctions 4600 interconnected with ELR segments 5320 (as will be described in further detail below with reference to Figure 53-A).

[00321] Generally, speaking ELR QUID 4900 may be used to detect magnetic fields that flow through the interior area formed by ELR loop 4710 as would be appreciated. More particularly, ELR QUID 4900 may be used with a DC biasing circuit 5100A- as illustrated in Figure 51-A. DC biasing circuit 5100 utilizes a DC current 5120 to provide a bias current through each of the legs of ELR loop 4710 of ELR QUID 4900. In this configuration, ELR QUID 4900 is sometimes referred to as DC QUID 4900. In various implementations of the invention, the bias currents through the legs of in ELR loop 4710 are kept at or just below the critical current of barriers 4610A of Josephson junctions 4600 in ELR QUID 4900. A magnetic field flowing through the interior area formed by ELR loop 4710 causes the current in ELR loop 4710 to exceed the critical current of barrier 4610A-, thereby producing a voltage across barriers 4610 which can be detected and/or measured as would be appreciated. ELR QUIDs 4900 are generally more sensitive to magnetic fields than, for example, ELR QUIDs 4700 as would be appreciated.

[00322] A construction of ELR QUID 4900 in accordance with various implementations of the invention is now described in reference Figure 53-A. As would be appreciated, the following description may apply to various implementations of ELR QUIDs 4700, 4800. As illustrated in Figure 53-A, ELR QUID 4900 may be comprised of a plurality of ELR segments 5320. Each ELR segment 5320 may have a structure similar to that of nanowire segment 4110. In some implementations of the invention, ELR segments 5320 may have dimensions larger, and in many cases substantially larger, than those of nanowire segments 4110. In some implementations of the invention, ELR segments 5320 comprise nanowire segments 4110. In some implementations of the invention, ELR segments 5320 comprise an ELR material such as those described above.

[00323] In some implementations of the invention, ELR QUID 4900 may comprise feeds 4810 formed from an ELR material such as those described above. In some

implementations of the invention, ELR QUID 4900 may comprise feeds 4810 formed from a material different from ELR material. In some implementations of the invention, ELR QUID 4900 may comprise feeds 4810 formed from a conductive material. In some implementations of the invention, ELR QUID 4900 may comprise feeds 4810 formed from a conductive metal. In some implementations of the invention, ELR QUID 4900 may comprise one feed 4810 formed from one material and another feed 4810A formed from another material.

[00324] In some implementations of the invention, various interfaces 5310 (illustrated as an interface 5310A, an interface 5310B, and an interface 5310C) may be used between ELR segments 5320 to form ELR loop 4710 as would be appreciated. (As would be appreciated, not all interfaces 5310 in ELR loop 4710 are illustrated for convenience.) According to various implementations of the invention, interfaces 5310 represent a transition between an orientation of crystalline structure of one ELR segment 5320 and that of another ELR segment 5320.

[00325] ELR QUIDs 4700, 4800, 4900 (henceforth referenced interchangeably as ELR QUIDs) often find their way into a variety of circuits and/or applications. For example, both ELR QUIDs 4700 and ELR QUIDs 4900 may be used to form very sensitive magnetometers (such as that illustrated in Figure 52A-A and discussed below). Depending on a sophistication of the biasing, amplification and feedback circuits employed (not otherwise illustrated) as would be appreciated, magnetometers may be formed that detect magnetic fields able to detect on the order of one ten-billionth (10^{-10}) of the earth's magnetic field.

[00326] Figures 52A-A to 52C-A illustrate various gradiometers 5200 according to various implementations of the invention. Generally speaking, gradiometers 5200 are instruments capable of measuring changes or gradients in magnetic fields. Figure 52A-A illustrates a gradiometer 5200A (also referred to as a magnetometer 5200A) that uses an ELR QUID 4700, 4900 to measure a magnetic field through a loop of a loop circuit 5210A as would be appreciated. As would be appreciated, ELR QUID 4700, 4900 may be magnetically shielded.

[00327] Figure 52B-A illustrates a gradiometer 5200B that uses an ELR QUID 4700 to measure a first derivative of the magnetic field through loops of a loop circuit 5210B as would be appreciated. More particularly, the two loops of loop circuit 5210B are configured to be equal in size, parallel to one another, and wound with opposite senses so that the currents induced in each loop cancel one another in the presence of a

uniform field. With such a configuration, the loops of loop circuit 5210B capture the difference between the loops as would be present in a changing field.

[00328] Figure 52C-A illustrates a gradiometer 5200C that uses an ELR QUID 4700 to measure a second derivative of the magnetic field through loops of a loop circuit 5210C as would be appreciated. More particularly, the four loops of loop circuit 5210C are configured to be equal in size, parallel to one another, and wound as illustrated so that the currents induced in each loop cancel one another in the presence of a uniformly changing field. With such a configuration, the loops of loop circuit 5210B capture the rate of change in the field through the loops.

[00329] Figure 53-A illustrates, in further detail, an exemplary ELR QUID 5300 according to various implementations of the invention. As illustrated, ELR QUID 5300 may be comprised of a plurality of ELR segments 5320 coupled together at exemplary intersections 5310 (illustrated in Figure 53-A as a potential intersection 5310A, a potential intersection 5310B, or a potential intersection 5310C). For example, two ELR segments 5320 may form intersection 5310 via one of potential intersections 5310A, 5310B, or 5310C. In some implementations of the invention, potential intersections 5310A and 5310C form perpendicular intersections between two ELR segments 5320; whereas, potential intersection 5310B forms a 45% intersections between two ELR segments 5320; and other potential intersections are possible as would be appreciated. As, one or more barriers 4610 (two are illustrated in Figure 53-A) are disposed between two ELR segments 5320 to form Josephson junctions 4600. As also illustrated, a plurality of ELR segments 5320 form a loop 4710, the loop having at least one barrier 4610 disposed between two of the plurality of ELR segments 5320.

[00330] In some implementations of the invention, two or more ELR QUIDs may be coupled together in parallel. In some implementations of the invention, two or more ELR QUIDs may be coupled together in series. In some implementations of the invention, two or more ELR QUIDs may be coupled together in series and also coupled in parallel with at least one other ELR QUID. In some implementations of the invention, an N-by-M matrix of ELR QUIDs may be formed on a surface (planar or otherwise) as a sensor matrix, capable of sensing, measuring, and/or locating various fields within the N-by-M matrix. In some implementations of the invention, an N-by-M-by-L lattice of ELR QUIDs may be formed as a sensor lattice, capable of sensing, measuring, and/or locating various fields within the volume of the N-by-M-by-L lattice. Various other configurations of ELR QUIDs may be formed as would be appreciated.

[00331] Because of their sensitivity, ELR QUIDs may be used to measure susceptance of materials, to non-destructively evaluate defects in metals, for geophysical surveying, for microscopic magnetic observations, and for biological measurements. The improved operating characteristics of the ELR materials utilized by ELR QUIDs of various implementations of the invention open widespread use of such ELR QUIDs in the field of medical and mental diagnostics and other applications where the measured sample must be maintained well above cryogenic temperatures.

[00332] In some implementations, a QUID that includes modified ELR materials may be described as follows:

[00333] An ELR QUID comprising: an ELR loop comprising an ELR material having improved operating characteristics and a Josephson junction.

[00334] An ELR QUID comprising: an ELR loop comprising an ELR material having a critical temperature greater than 150K and a barrier material, wherein the ELR material and the barrier material form at least one Josephson junction in the ELR loop.

[00335] An ELR QUID comprising: a plurality of ELR segments arranged to form an ELR loop, the ELR segments formed from an ELR material having a critical temperature greater than 150K; and a barrier disposed between two of the ELR segments to form a Josephson junction in the ELR loop.

[00336] An ELR QUID comprising: an ELR loop comprising a modified ELR material and a Josephson junction, wherein the modified ELR material comprises a first layer of ELR material and a second layer of modifying material bonded to the ELR material of the first layer, where the modified ELR material has improved operating characteristics over those of the ELR material alone.

[00337] An ELR QUID comprising: an ELR loop comprising a modified ELR material having a critical temperature greater than 150K and a barrier material, wherein the ELR material and the barrier material form at least one Josephson junction in the ELR loop, wherein the modified ELR material comprises a first layer of ELR material and a second layer of modifying material bonded to the ELR material of the first layer.

[00338] An ELR QUID comprising: a plurality of ELR segments arranged to form an ELR loop, the ELR segments formed from a modified ELR material, wherein the modified ELR material comprises a first layer of ELR material and a second layer of modifying material bonded to the ELR material of the first layer, where the modified ELR material has improved operating characteristics over those of the ELR material alone; and a barrier

disposed between two of the ELR segments to form a Josephson junction in the ELR loop.

[00339] An asymmetric ELR QUID comprising: an ELR loop comprising a ELR material and a Josephson junction, wherein the ELR material has improved operating characteristics, wherein the ELR loop has a first leg and a second leg, wherein the first leg carries more current than the second leg.

[00340] A circuit comprising: an ELR QUID comprising an ELR loop comprising a modified ELR material and a Josephson junction; and an inductor coupled to the ELR QUID, wherein an alternating current flowing through the inductor induces a current in the ELR loop of the ELR QUID.

[00341] A circuit comprising: an ELR QUID comprising an ELR loop comprising a modified ELR material and a Josephson junction, the ELR QUID having at least one feed for introducing a current into the ELR loop; a source for providing the current to the ELR QUID through the feed; and an input coil that senses a sensed current and that induces an induced current in the ELR QUID.

[00342] A magnetometer comprising: an ELR QUID comprising an ELR loop comprising a modified ELR material and a Josephson junction; an inductor; and a sensing loop coupled to the inductor, wherein a field flowing through the sensing loop provides a current to the inductor, and wherein the current through the inductor induces a second current in the ELR loop of the ELR QUID.

[00343] A gradiometer comprising: an ELR QUID comprising an ELR loop comprising a modified ELR material and a Josephson junction; and a sensing circuit comprising: an inductor, a first loop coupled to the inductor, and a second loop coupled to the first loop and the inductor, wherein the first loop is substantially the same size as the second loop, wherein the first loop is parallel to and disposed along a concentric axis of the second loop, and wherein the first loop is wound around the concentric axis in a direction opposite that of the second loop, wherein the first loop and the second loop provide a current to the inductor, wherein the current corresponds to a difference between a field flowing through the first loop and a field flowing through the second loop, and wherein the current through the inductor induces a second current in the ELR loop of the ELR QUID.

[00344] A gradiometer comprising: an ELR QUID comprising an ELR loop comprising a modified ELR material and a Josephson junction; and a sensing circuit comprising: an inductor, a first loop coupled to the inductor, and a second loop coupled to the first loop,

a third loop coupled to the second loop, a fourth loop coupled to the third loop and the inductor, wherein the first loop, the second loop, the third loop and the fourth loop are substantially the same size, wherein the first loop, the second loop, the third loop and the fourth loop are substantially are substantially parallel to one another, wherein the first loop, the second loop, the third loop and the fourth loop share a concentric axis, wherein the first loop is wound around the concentric axis in a direction opposite that of the second loop, wherein the third loop is wound around the concentric axis in a direction opposite that of the fourth loop, wherein the first loop, the second loop, the third loop, and the fourth loop provide a current to the inductor, wherein the current corresponds to a difference between a first difference and a second difference, the first difference corresponding to a difference between a field flowing through the first loop and a field flowing through the second loop, and the second difference corresponding to a difference between a field flowing through the third loop and a field flowing through the fourth loop, and wherein the current through the inductor induces a second current in the ELR loop of the ELR QUID.

[00345] A circuit comprising: a plurality of ELR QUIDs coupled in series with one another, each of the plurality of ELR QUIDs comprising an ELR loop comprising a modified ELR material and a Josephson junction.

[00346] A circuit comprising: a plurality of ELR QUIDs coupled in parallel with one another, each of the plurality of ELR QUIDs comprising an ELR loop comprising a modified ELR material and a Josephson junction.

[00347] A circuit comprising: a plurality of series ELR QUID arrays coupled in parallel with one another, each of the plurality of series ELR QUID arrays comprising a plurality of ELR QUIDs coupled in series with one another, each of the plurality of ELR QUIDs comprising an ELR loop comprising a modified ELR material and a Josephson junction.

[00348] A circuit comprising: a plurality of parallel ELR QUID arrays coupled in series with one another, each of the plurality of parallel ELR QUID arrays comprising a plurality of ELR QUIDs coupled in parallel with one another, each of the plurality of ELR QUIDs comprising an ELR loop comprising a modified ELR material and a Josephson junction.

[00349] A circuit comprising: an ELR QUID matrix comprised of N rows and M columns of ELR QUIDs, each of the plurality of ELR QUIDs comprising an ELR loop comprising a modified ELR material and a Josephson junction.

[00350] A circuit comprising: an ELR QUID lattice disposed in a volume, the ELR QUID comprised of L matrices comprised of N rows and M columns of ELR QUIDs disposed at

intervals in each matrix, each of the plurality of ELR QUIDs comprising an ELR loop comprising a modified ELR material and a Josephson junction, wherein the modified ELR material comprises a first layer of ELR material and a second layer of modifying material bonded to the ELR material of the first layer, where the modified ELR material has improved operating characteristics over those of the ELR material alone.

Chapter 4 – Medical Devices formed of ELR Materials

[00351] This chapter of the description refers to Figures 1-36 and Figures 37-A through Figure 59-A; accordingly all reference numbers included in this section refer to elements found in such figures.

[00352] Because of their sensitivity, ELR QUIDs may be used to measure susceptance of materials, to non-destructively evaluate defects in metals, for geophysical surveying, for microscopic magnetic observations, and for biological measurements. The improved operating characteristics of the ELR materials utilized by ELR QUIDs of various implementations of the invention open widespread use of such ELR QUIDs in the field of medical and mental diagnostics and other applications where the measured sample must be maintained well above cryogenic temperatures.

[00353] Figure 54-A illustrates an exemplary MRI system 5410, according to various implementations of the invention. In some implementations of the invention, MRI system 5410 may be controlled from an operator console 5412 which may include, without limitation, an input device 5413, a control panel 5414, and a display screen 5416. In some implementations of the invention, input device 5413 can include, without limitation, a mouse, a joystick, a keyboard, a track ball, a touch activated screen, a light wand, a voice control, or any similar or equivalent input device, and may be used for interactive geometry prescription.

[00354] In some implementations of the invention, operator console 5412 communicates via a link 5418 with a separate computer system 5420 that allows an operator to control the production and display of images on display screen 5416. In some implementations of the invention, computer system 5420 includes a number of modules that communicate with each other through a backplane 5420A. These modules may include, without limitation, an image processor module 5422, a CPU module 5424 and a memory module 5426, known in the art as a frame buffer for storing image data arrays. In some implementations of the invention, computer system 5420 is linked to disk storage 5428 and a tape drive 5430 for storage of image data and programs.

[00355] In some implementations of the invention, computer system 5420 communicates with a separate system control 5432 through a high speed serial link 5434. In some implementations of the invention, system control 5432 includes a set of modules connected together by a backplane 5432a. These modules may include, without limitation, a CPU module 5436A and a pulse generator module 5438A that connects to operator console 5412 through a serial link 5440, through which system control 5432 may receive commands from the operator to indicate the scan sequence that is to be performed. In some implementations of the invention, pulse generator module 5438 operates the system components to carry out the desired scan sequence and produces data which indicates the timing, strength and shape of the RF pulses produced, and the timing and length of the data acquisition window. Pulse generator module 5438 connects to a set of gradient amplifiers 5442 to indicate the timing and shape of the gradient pulses that are produced during the scan. In some implementations of the invention, pulse generator module 5438 can also receive patient data from a physiological acquisition controller 5444 that receives signals from a number of different sensors connected to the patient, such as ECG signals from electrodes attached to the patient. In some implementations of the invention, pulse generator module 5438 connects to a scan room interface circuit 5446, which receives signals from various sensors associated with the condition of the patient and the magnet system. In some implementations of the invention, through scan room interface circuit 5446, a patient-positioning system 5448 may receive commands to move the patient to the desired position for the scan. In some implementations of the invention, patient positioning system 5448 may control patient position such that the patient is continuously or incrementally translated during data acquisition.

[00356] In some implementations of the invention, the gradient waveforms produced by pulse generator module 5438 are applied to gradient amplifiers 5442 having G_x, G_y, and G_z amplifiers. Each gradient amplifier 5442 excites a corresponding physical gradient coil in a gradient coil assembly generally designated 5450 to produce the magnetic field gradients used for spatially encoding acquired signals. In some implementations of the invention, gradient coil assembly 5450 may form part of a magnet assembly 5452 which includes a polarizing magnet 5454 and a whole-body RF coil 5456. In some implementations of the invention, a transceiver module 5458 in system control 5432 produces pulses that are amplified by an RF amplifier 5460, which is coupled to whole-body RF coil 5456 by a transmit/receive switch 5462. The resulting signals

emitted by the excited nuclei in the patient may be sensed by the same whole-body RF coil 5456 and coupled through the transmit/receive switch 5462 to a preamplifier 5464. The amplified MR signals are demodulated, filtered, and digitized in the receiver section of transceiver module 5458. Transmit/receive switch 5462 is controlled by a signal from pulse generator module 5438 to electrically connect RF amplifier 5460 to whole-body RF coil 5456 during the transmit mode and to connect preamplifier 5464 to whole-body RF coil 5456 during the receive mode. In some implementations of the invention, transmit/receive switch 5462 can also allow a separate RF coil (for example, a surface coil) to be used in either the transmit or receive mode.

[00357] The MR signals picked up by whole-body RF coil RF coil 5456 are digitized by transceiver module 5458 and transferred to a memory module 5466 in system control 5432. A scan is complete when an array of raw k-space data has been acquired in memory module 5466. This raw k-space data is rearranged into separate k-space data arrays for each image to be reconstructed, and each of these is input to an array processor 5468, which performs a Fourier transform of the data into an array of image data. This image data is conveyed through serial link 5434 to computer system 5420 where it is stored in memory, such as disk storage 5428A. In response to commands received from operator console 5412, this image data may be archived in long term storage, such as on tape drive 5430, or it may be further processed by image processor 5422, conveyed to operator console 5412 and presented via display 5416.

[00358] Various implementations of the invention include methods and systems suitable for use with MRI system 5410, or any similar or equivalent system for obtaining magnetic resonance images.

[00359] Figures 55A-A illustrates exemplary MRI magnets 5500A and 5500B employing various ELR materials, including modified ELR materials, apertured ELR materials, and/or new ELR materials, in accordance with various implementations of the invention. Magnets 5500A and 5500B generate magnetic field B_0. During an MRI procedure, the magnetic field B_0 aligns certain atoms of a subject (e.g., a human body, etc.) that are distributed within the internal body tissues of the subject. In some implementations, the subject may be placed along a path substantially parallel to the magnetic field B_0 such that the subject is placed through magnets 5500 (such as in "closed" bore MRI applications). In some implementations, the subject may be placed along a path substantially perpendicular to the magnetic field B_0 such that the subject is placed between magnets 5500 (such as in "open" MRI applications).

[00360] Although a pair of MRI magnets 5500 are illustrated in Figures 55A-A, 55B-A, and 55C-A, any number of magnets may be used as would be appreciated. Furthermore, although MRI magnet 5500 is illustrated in Figure 5500 as toroidal shaped, other configurations may be used as would be appreciated.

[00361] Figure 55B-A illustrates a cross-section of MRI magnets 5500A and 5500B and the magnetic field B_0 they generate, according to various implementations of the invention.

[00362] Figure 55C-A illustrates a cross section of a portion of magnet 5500A, according to various implementations of the invention. In some implementations of the invention, magnet 5500A may include, without limitation, a housing 5520, an ELR material 5510, and a switch 5530 coupled to a power supply (not illustrated in Figure 55C-A).

[00363] In some implementations of the invention, windings of ELR material 5510 are made about housing 5520. In some implementations of the invention, housing 5520 may include a cavity that includes windings of ELR material 5510. In some implementations of the invention, housing 5520 may house or otherwise include windings of ELR material 5510.

[00364] In some implementations of the invention, switch 5530 may be coupled to a power supply that provides current to ELR material 5510, thereby generating magnetic field B_0. In some implementations of the invention, ELR material 5510 may be configured as a tape or wire. In some implementations, ELR material may be configured as a plurality of nanowire segments such as nanowire segment 4110. In some implementations of the invention, ELR material 5510 may be configured as nanowire coils such as, but not limited to, nanowire coils 4200, 4300, and/or 4400. In various implementations of the invention ELR material 5510 may comprise modified ELR materials 1060, apertured ELR materials, and/or other new ELR materials in accordance with various implementations of the invention.

[00365] In some implementations of the invention, magnet 5500 operates with improved operating characteristics such as operating at temperatures above cryogenic temperatures. In some implementations of the invention, magnet 5500 operates with improved operating characteristics such as operating at temperatures above 150K. In some implementations, magnet 5500 may generate magnetic field B_0 having magnetic flux densities above at least 1.0 T, 1.5 T, 3.0 T, 4.5 T, or 6.0T without cryogenic coolants.

[00366] Figure 56-A illustrates a cross-sectional view of an MRI magnet assembly 5000, according to various implementations of the invention. Although MRI magnet assembly

5000 is illustrated in Figure 50-A as a toroidal bore-type magnet assembly, other configurations, such as a helix, oval, or other shape, may be used as would be appreciated. For example, open or portable MRI configurations using a magnet with ELR materials may be used.

[00367] According to various implementations of the invention, MRI magnet assembly 5600 may include, without limitation, an ELR material 5610, a housing 5620, an insulating layer 5630, a cavity 5640, a cold head 5650, and a bore 5660A. In some implementations of the invention, ELR material 5610A may comprise modified ELR material 1060, an apertured ELR material, and/or new ELR material in accordance with various implementations of the invention. In some implementations of the invention, ELR material 5610 may be configured as a tape or wire. In some implementations of the invention, ELR material 5610 may be configured as a nanowire such as a plurality of nanowire segments 4110. In some implementations of the invention, ELR material 5610 may be configured as nanowire coils such as nanowire coils 4200, 4300, and/or 4400.

[00368] In some implementations of the invention, ELR material 5610 is disposed within cavity 5640 of housing 5620. In some implementations of the invention, cavity 5640 is filled with a coolant such that magnet 5610 is immersed in the coolant. In some implementations of the invention, the coolant may include a cryogenic coolant or a non-cryogenic coolant. In these implementations, cold head 5650 includes a structure for maintaining the coolant as would be appreciated. In some implementations of the invention, cavity 5640 may be filled with a coolant such as a gas (e.g., ambient air, or other gases) or a liquid (e.g., water, carbon dioxide, ammonia, Freon™, a water-glycol mixture, a water-betaine mixture, or other liquids) or other coolants.

[00369] In some implementations of the invention (not illustrated in Figure 56-A), magnet 5610 may be disposed within or on a solid material.

[00370] According to various implementations of the invention, ELR material 5610 operates with improved operating characteristics such as operating at temperatures above cryogenic temperatures. In some implementations of the invention, ELR material 5610 operates with improved operating characteristics such as operating at temperatures above 150K. Thus, without a cryogenic coolant, MRI magnet assembly 5100 may produce a magnetic field B_0 substantially comparable to or better than that of conventional superconducting magnets that operate using cryogenic coolants (e.g., liquid helium , liquid nitrogen, or other cryogenic coolants). In some implementations of the invention, MRI magnet assembly 5100 generates a magnetic field B_0 substantially

comparable to conventional superconducting magnets that operate using cryogenic coolants such as liquid helium or liquid nitrogen.

[00371] Figure 57-A is a block diagram illustrating an exemplary MRI circuitry 5700, according to various implementations of the invention. According to various implementations of the invention, MRI circuitry 5700 may include, without limitation, a converter 4500, a filter 5702, an Analog-to-Digital Converter (ADC) 5704, a digital up-converter (DUC) 5706, a filter 5708, a processor/detector 5710, a filter 5712, a digital down-converter (DDC) 5714, a digital equalizer 5716, a digital-to-analog converter (DAC) 5718, and a high power amplifier (HPA) 5720.

[00372] In some implementations of the invention, filters 5702 and 5708, ADC 5704, and digital up-converter 5706 may be configured as a receiver circuit as would be appreciated. Similarly, in some implementations of the invention, filter 5712, digital down-converter 5714, digital equalizer 5716, DAC 5718 and HPA 5720 may be configured as a transmitter circuit as would be appreciated. In some implementations of the invention, the foregoing receiver circuit and transmitter circuit may be configured as a transceiver circuit as would be appreciated.

[00373] In some implementations of the invention, one or more components, or one or more elements (e.g., as interconnects, etc.) of the one or more components, of the receiver circuit, transmitter circuit, or transceiver circuit may comprise (i.e., be constructed from) an improved ELR material such as modified ELR material 1060, an apertured ELR material, and/or a new ELR material in accordance with various implementations of the invention. In some implementations of the invention, improved ELR material may be configured as an ELR nanowire and may include a plurality of nanowire segments 4110. In some implementations of the invention, ADC 5704 may include a low noise and high sensitivity digitizer front-end, such as an ELR QUID detector that employs one or more ELR QUIDs (e.g., ELR QUID 4700, ELR QUID 4800, ELR QUID 4900). In some implementations, using an ELR QUID detector in MRI increases the resolution of RF detection. In some implementations, using high Q ELR filters reduces insertion loss and bandwidth, and improves SNR. In some implementations of the invention, the ELR QUID detector is sensitive enough to eliminate the need for a low-noise amplifier.

[00374] In some implementations of the invention, processor 5710 may be configured to receive voltage induced by converter 4500. Processor 5710 may be configured to process information based on various components (which may be formed of the

improved ELR material) of the receiver circuit and/or transmitter circuit operating in an ELR state. This may improve signal-processing speed, thereby reducing scan times. In some implementations of the invention, processor 5710 may be configured to control voltage delivered to converter 4500 to produce an RF pulse.

[00375] Figure 58-A illustrates a cross-sectional view of an MRI apparatus 5800, according to various implementations of the invention. According to various implementations of the invention, MRI apparatus 5800 may include, without limitation, a housing 5802, a magnet 5810, a gradient coil 5820, an RF coil 5830, a magnet bore 5860, circuitry 5870, an RF coil controller 5875, a gradient coil controller 5880, and a computing device 5890. In some implementations of the invention, circuitry 5870 may include one or more components and/or one or more elements of circuitry 5700 illustrated in Figure 57-A. In some implementations of the invention, computing device 5890 may be coupled to RF coil controller 5875, gradient coil controller 5880A and circuitry 5870. Computing device 5890 may control via RF coil controller 5875 and gradient coil controller 5880 electromagnetic fields emitted by gradient coil 5820 and/or RF coil 5830. In some implementations of the invention, computing device 5890 controls circuitry 5870.

[00376] In some implementations of the invention, various components of MRI apparatus 5800 may employ improved ELR materials described herein. For example, magnet 5810, gradient coil 5820, RF coil 5830, and/or circuitry 5870 may employ improved ELR materials disclosed herein.

[00377] By including various components that employ such improved ELR materials disclosed herein, MRI apparatus 5800 may achieve better performance than conventional MRI scanners that do not employ such improved ELR materials. For example, MRI apparatus 5800 may achieve improved SNR, higher resolution, simplified and reliable cooling, reduced size, larger opening (magnet bore 5860) for the subject, and higher energy efficiency.

[00378] In some implementations of the invention, magnet 5810 may comprise a improved ELR material, such as modified ELR material 1060, an apertured ELR material, and/or a new ELR material in accordance with various implementations of the invention. In some implementations of the invention, magnet 5810 can include magnet 5500A illustrated in Figure 55C-A.

[00379] By using various improved ELR materials disclosed herein, magnet 5810 exhibits improved operating characteristics over conventional MRI magnets. As

previously noted, such improved operational characteristics include higher temperatures of operation while providing magnetic intensities from 0.5 T to 3.0 T and greater. By operating at higher temperatures, magnet 5810 requires smaller or no cooling systems thereby facilitating, among other advantages, a more compact design of MRI apparatus 5800 and less operational cost. For example, less space devoted to cooling systems allows larger bore openings through which the subject may be placed. In this manner, more open systems and therefore larger patients or patients on gurneys may be scanned. For example, a gurney or other structure on which the subject lies may be wheeled or otherwise placed inside MRI apparatus 5800 for scanning the subject or MRI apparatus 5800 may itself be wheeled or placed around the gurney. Because of the larger opening facilitated by using magnet 5810, MRI apparatus 5800 is not limited to the rigid table of conventional MRI scanners.

[00380] In some implementations of the invention, gradient coil 5820 may comprise a improved ELR material such as modified ELR material 1060, an apertured ELR material, and/or a new ELR material in accordance with various implementations of the invention. By using various improved ELR materials disclosed herein, gradient coil 5820 exhibits improved operating characteristics over conventional gradient coils. In some implementations of the invention, RF coil 5830 may comprise an improved ELR material such as modified ELR material 1060, an apertured ELR material, and/or a new ELR material in accordance with various implementations of the invention. By using various improved ELR materials disclosed herein, RF coil 5830 exhibits improved operating characteristics over conventional RF coils. For example, using improved ELR materials, gradient coil 5820 and/or RF coil 5830 may reduce or eliminate resistive losses, and increase selectivity and resolution over conventional coils.

[00381] In some implementations of the invention, RF coil 5830 may include various converters disclosed herein such as converter 4500.

[00382] In some implementations of the invention, circuitry 5870 may include an ELR QUID detector that employs one or more ELR QUIDs (e.g., ELR QUID 4700, ELR QUID 4800, ELR QUID 4900). In some implementations, using an ELR QUID detector in MRI increases the resolution and sensitivity of RF detection. In some implementations, using high Q ELR filters reduces insertion loss and bandwidth, and improves SNR.

[00383] In some implementations, enhanced transmission and detection capabilities resulting from use of improved ELR materials (such as those described above) facilitates use of low field (e.g., less than 0.5 T) MRI while achieving higher resolution than

conventional low field MRI. In these implementations, low field MRI allows portability, a larger, less restrictive field of measurement, reduction of chemical shift and a dramatically lower system cost. Chemical shift refers to the resonance frequency variations resulting from intrinsic magnetic shielding of anatomic structures. Molecular structure and electron orbital characteristics produce fields that shield the main magnetic field and give rise to distinct peaks in the magnetic resonance spectrum. In the case of proton spectra, peaks correspond to water and fat, and in the case of breast imaging, silicone material. Lower frequencies of about 3.5 parts per million ("ppm") for protons in fat and 5.0 ppm for protons in silicone occur, compared to the resonance frequency of protons in water. Since resonance frequency increases linearly with field strength, the absolute difference between the fat and water resonance also increases, making high field strength magnets more susceptible to chemical shift artifact. Thus, using low field MRI while maintaining high resolution may reduce or eliminate effects of chemical shift.

[00384] In some implementations of the invention, low field MRI relaxes the requirement for a closely coupled arrangement of gradient coil 5820 and/or RF coil 5830, thus opening up the enclosure in which the subject is scanned. In these implementations, MRI apparatus 5800 may be more portable such as being wheeled/positioned so that it encloses a gurney or other structure carrying the subject. As would be appreciated, the gurney or other structure may be made from MRI-inert material.

[00385] Figure 59-A illustrates a portable MRI apparatus system 5900, according to various implementations of the invention. In some implementations of the invention, portable MRI apparatus system 5900 may include, without limitation, a portable MRI apparatus 5910, a sensor 5920, an ELR QUID detector 5930, a magnet 5950, a gradient coil 5960, an RF coil 5970, and a computing device 5940. In some implementations of the invention, ELR QUID detector 5930 (e.g., ELR QUID 4700, 4800, 4900, etc.) employs improved ELR materials thereby having improved operating characteristics as described above. In some implementations, computing device 5940 controls the magnetic field from magnet 5950. In some implementations, computing device 5940 controls the gradient field from gradient coil 5960. In some implementations, computing device 5940 controls the excitation pulses from RF coil 5970.

[00386] In some implementations of the invention, computing device 5940 may be coupled to magnet 5950 and ELR QUID detector 5930. In some implementations of the invention, computing device 5940 causes magnet 5950 to generate a magnetic field for low field MRI scanning. In some implementations of the invention, magnet 5950 may

include a low-intensity magnet that produces the low intensity field of less than approximately 0.5 Tesla, which is facilitated by the sensitivity of ELR QUID detector 5930. In some implementations of the invention, gradient coil 5960 may generate a gradient field that allows location of certain atoms of the subject. In some implementations of the invention, RF coil 5970 may generate an excitation pulse, which cause a resonance signal from atoms of the subject.

[00387] According to various implementations of the invention, sensor 5920 may include, without limitation, a magnetometer, gradiometer, a flux transformer, or other sensing component that senses a resonance signal caused by the low-intensity magnetic field generated by magnet 5950. ELR QUID detector 5930 may receive and process the sensed signal as would be appreciated.

[00388] Unlike conventional devices that use SQUID detectors, portable MRI apparatus 5910 does not require using a cryogenic coolant/cooler to cool ELR QUID detector 5930. Accordingly, among other benefits such as higher image quality, lower cost, and easier maintenance, portable MRI apparatus 5910 may be easily movable without requiring a cryogenic cooler.

[00389] As illustrated in Figure 59-A, for example, portable MRI apparatus 5910 may be positioned adjacent to a structure 5902 such as, without limitation, a gurney, an examination table or wall/floor/ceiling. In some implementations of the invention, portable MRI apparatus 5910 is rigidly coupled to structure 5902. In other implementations, portable MRI apparatus 5910 may be moved about structure 5902. For example, structure 5902 may be removably placed inside MRI apparatus 5910 and/or MRI apparatus 5910 may be removably placed around structure 5902. In these implementations, magnet 5950 may itself be portable, be rigidly coupled to a housing of portable MRI apparatus 5910 (not illustrated in Figure 59-A) or may be rigidly coupled to structure 5902 or other structure.

[00390] In some implementations of the invention, structure 5902 may include opposing surfaces 5901 and 5903. Surface 5901 and/or surface 5903 may have a substantially flat, curved, or other shape based on site or other specifications. In some implementations of the invention, a subject such as a patient may be scanned while on or near surface 5901. For example, a patient may stand adjacent to, lie on or underneath surface 5901, or place a body part such as an arm, a head, or other extremity near, on or underneath surface 5901. In some implementations of the invention, portable MRI apparatus 5910 may be placed adjacent to surface 5903 (i.e., on a side of structure 5902 opposite the

scanned subject). In this manner, an open MRI procedure may be achieved, where the subject stands near, lies on, or lies underneath structure 5902 without scanning instrumentation or components of portable MRI apparatus 5910 adjacent to the side of the subject opposite portable MRI apparatus 5910. In these implementations, medical procedures such as surgery or examinations can be assisted by images produced by portable MRI apparatus 5910.

[00391] According to various implementations of the invention, magnet 5950, gradient coil 5960 and/or RF coil 5970 employs improved ELR materials thereby having improved operating characteristics as described herein. In these implementations, employing improved ELR materials facilitates various configurations of magnet 5950, gradient coil 5960, and/or RF coil 5970. For example, the tight coupling among conventional magnets, gradient coils and RF coils required for conventional MRI scanners is relaxed using magnet 5950, gradient coil 5960 and/or RF coil 5970. These relaxed configurations may result in a larger bore opening than conventional scanners that use conventional magnets, gradient coils, and RF coils that do not employ improved ELR materials disclosed herein. The larger bore opening facilitates portability of portable MRI apparatus 5910 (such as being removable about structure 5902 or vice versa) as well as accommodation of larger subjects.

[00392] In some implementations of the invention, portable MRI apparatus 5910 may include active and/or passive electromagnetic shielding (not illustrated) as would be appreciated. In some implementations of the invention, portable MRI apparatus 5910 may be used in a "clean" or otherwise shielded room. In some implementations of the invention (not illustrated) structure 5902 may include one or more shielding elements.

[00393] Although illustrated as being positioned on a side of structure 5902 opposite the subject, portable MRI apparatus 5910 may be placed at various locations relative to the subject due to the portability of portable MRI apparatus 5910. Furthermore, any combination of sensor 5920, ELR QUID detector 5930, computing device 5940, magnet 5950, gradient coil 5960, and RF coil 5970 may be housed in a single housing (as illustrated in Figure 54-A, for example), or in multiple housings. For example, magnet 5950 may also be portable, be included with portable MRI apparatus 5910, or may be coupled to structure 5902.

[00394] As would be appreciated, computing device 5940 may include a memory that stores instructions that configure one or more processors (not illustrated in Figure 59-A)

that control magnet 5950 and generates an MRI image based on processing by ELR QUID detector 5930.

[00395] In some implementations, a medical device that includes modified ELR materials may be described as follows:

[00396] A magnetic resonance imaging (MRI) magnet, comprising: an ELR material, the ELR material having an improved operating characteristic; wherein the ELR material propagates a current that generates a magnetic field during an MRI procedure, wherein the magnetic field causes certain atoms in a body of a subject to align.

[00397] A magnetic resonance imaging (MRI) magnet assembly, comprising: a housing; and an MRI magnet coupled to the housing, the MRI magnet comprising: an ELR material having an improved operating characteristic, wherein the ELR material generates a magnetic field during an MRI procedure, wherein the magnetic field causes certain atoms in a body of a subject to align.

[00398] A magnetic resonance imaging (MRI) magnet, comprising: a wire comprising an ELR material, the ELR material having an improved operating characteristic; wherein the wire propagates a current that generates a magnetic field during an MRI procedure, wherein the magnetic field causes certain atoms in a body of a subject to align.

[00399] A magnetic resonance imaging (MRI) magnet assembly, comprising: a housing; and an MRI magnet coupled to the housing, the MRI magnet comprising an ELR material having an improved operating characteristic, wherein the ELR material generates a magnetic field during an MRI procedure, wherein the magnetic field causes certain atoms in a body of a subject to align.

[00400] A Magnetic Resonance Imaging (MRI) magnet, comprising: an ELR nanowire, the ELR nanowire configured to conduct an electrical current to generate a magnetic field during an MRI procedure, wherein the ELR nanowire comprises: an ELR material having three dimensional parameters, including a length, a width, and depth, wherein at least one of the dimensional parameters is less than a threshold such that the ELR nanowire does not exhibit at least one superconducting phenomenon while operating with extremely low resistance.

[00401] A Magnetic Resonance Imaging (MRI) magnet assembly, comprising: a housing; and an MRI magnet coupled to the housing, the MRI magnet comprising: an ELR nanowire, the ELR nanowire configured to conduct an electrical current to generate a magnetic field during an MRI procedure, wherein the ELR nanowire comprises: an ELR material having three dimensional parameters, including a length, a width, and depth,

wherein at least one of the dimensional parameters is less than a threshold such that the ELR nanowire does not exhibit at least one superconducting phenomenon while operating with extremely low resistance.

[00402] A magnetic resonance imaging (MRI) magnet, comprising: a nanowire comprising an ELR material having an improved operating characteristic, wherein the nanowire propagates a current that generates a magnetic field during an MRI procedure, wherein the magnetic field causes certain atoms in a body of a subject to align.

[00403] A magnetic resonance imaging (MRI) magnet assembly, comprising: a housing; and an MRI magnet coupled to the housing, the MRI magnet comprising: a nanowire comprising an ELR material having an improved operating characteristic, wherein the nanowire generates a magnetic field during an MRI procedure, wherein the magnetic field causes certain atoms in a body of a subject to align.

[00404] A magnetic resonance imaging (MRI) magnet, comprising: an ELR nanowire contour, the ELR nanowire contour configured to conduct an electrical current to generate a magnetic field during an MRI procedure, wherein the magnetic field causes certain atoms in a body of a subject to align, wherein the ELR nanowire contour comprises: at least one ELR nanowire segment, each ELR nanowire segment comprising an ELR material having an improved operating characteristic.

[00405] A magnetic resonance imaging (MRI) magnet assembly, comprising: a housing; and an MRI magnet coupled to the housing, the MRI magnet comprising: an ELR nanowire contour, the ELR nanowire contour configured to conduct an electrical current to generate a magnetic field during an MRI procedure, wherein the magnetic field causes certain atoms in a body of a subject to align, wherein the ELR nanowire contour comprises: at least one ELR nanowire segment, each ELR nanowire segment comprising an ELR material having an improved operating characteristic.

[00406] A magnetic resonance imaging (MRI) magnet, comprising: an ELR nanowire coil, the ELR nanowire coil configured to conduct an electrical current to generate a magnetic field during an MRI procedure, wherein the magnetic field causes certain atoms in a body of a subject to align, wherein the ELR nanowire coil comprises: at least one ELR nanowire contour, each of the at least one ELR nanowire contours comprising a plurality of ELR nanowire segments, each of the plurality of ELR nanowire segments coupled to at least one other of the plurality of ELR nanowire segments to substantially form a polygon, each of the at least one ELR nanowire segments comprising an ELR material having an improved operating characteristic.

[00407] A magnetic resonance imaging (MRI) magnet assembly, comprising: a housing; and an MRI magnet coupled to the housing, the MRI magnet comprising: an ELR nanowire coil, the ELR nanowire coil configured to conduct an electrical current to generate a magnetic field during an MRI procedure, wherein the magnetic field causes certain atoms in a body of a subject to align, wherein the ELR nanowire coil comprises: at least one ELR nanowire contour, each of the at least one ELR nanowire contours comprising a plurality of ELR nanowire segments, each of the plurality of ELR nanowire segments coupled to at least one other of the plurality of ELR nanowire segments to substantially form a polygon, each of the at least one ELR nanowire segments comprising an ELR material having an improved operating characteristic.

[00408] A magnetic resonance imaging (MRI) nanowire converter comprising: at least one nanowire segment comprised of an improved ELR material, wherein the MRI nanowire converter either: induces a magnetic field when a current is applied to the at least one nanowire segment during an MRI procedure, wherein the electromagnetic field causes certain atoms in a body of a subject to align, or senses a resonance signal emitted by certain atoms in the body of the subject as certain aligned atoms become unaligned during the MRI procedure.

[00409] A magnetic resonance imaging (MRI) nanowire converter comprising: at least one nanowire segment comprised of an improved ELR material, wherein when exposed to a resonance signal during an MRI procedure, the MRI nanowire converter senses the resonance signal via the at least one nanowire segment and converts the sensed resonance signal to an alternating current that can be measured and used for imaging.

[00410] A magnetic resonance imaging (MRI) nanowire converter comprising: at least one nanowire segment comprised of an improved ELR material, wherein the MRI nanowire converter is electrically coupled to an alternating current source, wherein the MRI nanowire converter induces an electromagnetic field during an MRI procedure in response to the alternating current source, the induced electromagnetic field causes certain atoms in a body of a subject to align and subsequently emit a resonance signal as the certain atoms become unaligned, wherein the resonance signal can be detected and used for imaging.

[00411] A magnetic resonance imaging (MRI) nanowire converter comprising: an ELR material having an improved operating characteristic, wherein the MRI nanowire converter either: induces a magnetic field when a current is applied to the MRI nanowire converter during an MRI procedure, wherein the electromagnetic field causes certain

atoms in a body of a subject to align, or senses a resonance signal emitted by certain atoms in the body of the subject as certain aligned atoms become unaligned during the MRI procedure.

[00412] A magnetic resonance imaging (MRI) nanowire converter comprising: an ELR material having an improved operating characteristic, wherein when exposed to a resonance signal during an MRI procedure, the MRI nanowire converter senses the resonance signal and converts the sensed resonance signal to an alternating current that can be measured and used for imaging.

[00413] A magnetic resonance imaging (MRI) nanowire converter comprising: an ELR material having an improved operating characteristic, wherein the MRI nanowire converter is electrically coupled to an alternating current source, wherein the MRI nanowire converter induces an electromagnetic field during an MRI procedure in response to the alternating current source, the induced electromagnetic field causes certain atoms in a body of a subject to align and subsequently emit a resonance signal as the certain atoms become unaligned, wherein the resonance signal can be detected and used for imaging.

[00414] A Magnetic Resonance Imaging (MRI) transmitter circuit, comprising: a digital-to-analog converter (DAC) that generates an analog signal based on digital output of an MRI system; and a converter electrically coupled to the DAC, the converter comprising: an improved ELR material, wherein the converter induces a magnetic field when the analog signal is applied to the improved ELR material wherein the electromagnetic field causes certain atoms in a body of a subject to align.

[00415] A Magnetic Resonance Imaging (MRI) receiver circuit, comprising: a converter, comprising: an improved ELR material, wherein the converter senses a resonance signal emitted by certain atoms in a body of a subject as certain aligned atoms become unaligned during an MRI procedure; and an analog-to-digital converter (ADC) electrically coupled to the converter, wherein the ADC digitizes the resonance signal, wherein the digitized resonance signal is used to generate an MRI image.

[00416] A Magnetic Resonance Imaging (MRI) transceiver circuit, comprising: a converter, comprising: an improved ELR material, wherein during an MRI procedure, the converter: senses a resonance signal emitted by certain atoms in a body of a subject as certain aligned atoms become unaligned during an MRI procedure, or induces a magnetic field when an analog signal is applied to the improved ELR material wherein the electromagnetic field causes certain atoms in a body of a subject to align; and an

analog-to-digital converter (ADC) electrically coupled to the converter, wherein the ADC digitizes the resonance signal, wherein the digitized resonance signal is used to generate an MRI image; and a digital-to-analog converter (DAC) that generates the analog signal based on digital output of an MRI system.

[00417] A magnetic resonance imaging (MRI) scanner, comprising: an MRI magnet comprising an improved ELR material; an MRI RF converter configured to: induce a magnetic field when a current is applied to the MRI RF converter during an MRI procedure, wherein the electromagnetic field causes certain atoms in a body of a subject to align, and sense a resonance signal emitted by the certain atoms as they become unaligned during the MRI procedure; and an MRI detector that detects the sensed resonance signal from the MRI RF converter to generate an MRI image.

[00418] An MRI detector, comprising: an ELR QUID comprising an improved ELR material, wherein the ELR QUID detects a resonance signal emitted by certain aligned atoms in a body of a subject as they become unaligned during an MRI procedure.

[00419] An MRI detector, comprising: an ELR QUID comprising an ELR material having at least one improved operating characteristic, wherein the ELR QUID detects a resonance signal emitted by certain aligned atoms in a body of a subject as they become unaligned during an MRI procedure.

[00420] An MRI detector, comprising: an ELR QUID comprising a modified ELR material, the modified ELR material comprising an ELR material bonded to a modifying material, the modified ELR material having an improved operating characteristic over that of the ELR material alone, wherein the ELR QUID detects a resonance signal emitted by certain aligned atoms in a body of a subject as they become unaligned during an MRI procedure.

[00421] A portable MRI scanner, comprising: an MRI magnet comprising an improved ELR material, wherein the improved ELR material operates in an ELR state at temperatures greater than 150K such that the MRI magnet requires no cryogenic cooling during an MRI procedure, wherein a bore of the MRI magnet is enlarged such that the portable MRI scanner is removable about a structure on which a subject is scanned during the MRI procedure; an MRI RF converter configured to: induce a magnetic field when a current is applied to the MRI RF converter during the MRI procedure, wherein the electromagnetic field causes certain atoms in a body of a subject to align, and sense a resonance signal emitted by the certain atoms as they become unaligned during the MRI

procedure; and an MRI detector that detects the sensed resonance signal from the MRI RF converter to generate an MRI image.

[00422] A portable MRI scanner, comprising: an MRI magnet comprising an improved ELR material, wherein the improved ELR material operates in an ELR state at temperatures greater than 150K such that the MRI magnet requires no cryogenic cooling during an MRI procedure, wherein a bore of the MRI magnet is enlarged such that a structure on which a subject is scanned during the MRI procedure is removable from the portable MRI scanner; an MRI RF converter configured to: induce a magnetic field when a current is applied to the MRI RF converter during an MRI procedure, wherein the electromagnetic field causes certain atoms in a body of a subject to align, and sense a resonance signal emitted by the certain atoms as they become unaligned during the MRI procedure; and an MRI detector that detects the sensed resonance signal from the MRI RF converter to generate an MRI image.

[00423] A portable MRI scanner, comprising: a low intensity magnet that generates a low intensity magnetic field; an MRI RF converter configured to: induce a magnetic field when a current is applied to the MRI RF converter during an MRI procedure, wherein the electromagnetic field causes certain atoms in a body of a subject to align, and sense a resonance signal emitted by the certain atoms as they become unaligned during the MRI procedure; and an ELR QUID detector that detects the resonance signal.

[00424] A portable MRI scanner, comprising: an MRI magnet; an MRI gradient coil, comprising: an improved ELR material, wherein the MRI gradient coil conducts an electrical current to generate a gradient field during an MRI procedure, wherein the gradient field causes certain atoms in a body of a subject to spin at different speeds based on a location in the body of the certain atoms, wherein the improved ELR material allows a particular configuration of the MRI gradient coil that allows a bore of the MRI magnet to be enlarged; and an MRI detector that detects a resonance signal during an MRI procedure to generate an MRI image.

[00425] A portable MRI scanner, comprising: an MRI magnet; an MRI RF coil, comprising: an improved ELR material, wherein the MRI RF coil: induces a magnetic field when a current is applied to the MRI RF coil during an MRI procedure, wherein the electromagnetic field causes certain atoms in a body of a subject to align, or senses a resonance signal emitted by the certain atoms as they become unaligned during the MRI procedure, wherein the improved ELR material allows a particular configuration of the

MRI RF coil that allows a bore of the MRI magnet to be enlarged; and an MRI detector that detects a resonance signal during an MRI procedure to generate an MRI image.

[00426] A magnetic resonance imaging (MRI) gradient coil, comprising: an improved ELR material, wherein the MRI gradient coil conducts an electrical current to generate a gradient field during an MRI procedure, wherein the gradient field causes certain atoms in a body of a subject to spin at different speeds based on a location in the body of the certain atoms.

[00427] A magnetic resonance imaging (MRI) gradient coil, comprising: a nanowire comprising an improved ELR material, wherein the nanowire conducts an electrical current to generate a gradient field during an MRI procedure, wherein the gradient field causes certain atoms in a body of a subject to spin at different speeds based on a location in the body of the certain atoms.

[00428] A magnetic resonance imaging (MRI) apparatus, comprising an MRI magnet; an MRI RF coil that either: induces a magnetic field when a current is applied to the MRI RF coil during an MRI procedure, wherein the electromagnetic field causes certain atoms in a body of a subject to align, or senses a resonance signal emitted by the certain atoms as they become unaligned during the MRI procedure; and a gradient coil, comprising: an improved ELR material, wherein the MRI gradient coil conducts an electrical current to generate a gradient field during an MRI procedure, wherein the gradient field causes certain atoms in a body of a subject to spin at different speeds based on a location in the body of the certain atoms; and an MRI detector that detects the sensed resonance signal from the MRI RF coil to generate an MRI image.

[00429] A Magnetic Resonance Imaging (MRI) Radio Frequency (RF) coil, comprising: an improved ELR material, wherein during an MRI procedure the RF coil: induces a magnetic field when a current is applied to the at least one nanowire segment during an MRI procedure, wherein the electromagnetic field causes certain atoms in a body of a subject to align, or senses a resonance signal emitted by certain atoms in the body of the subject as certain aligned atoms become unaligned during the MRI procedure.

[00430] A Magnetic Resonance Imaging (MRI) Radio Frequency (RF) coil, comprising: an improved ELR material, wherein when exposed to a resonance signal during an MRI procedure, the RF coil senses the resonance signal converts the sensed resonance signal to an alternating current that can be measured and used for imaging.

[00431] A Magnetic Resonance Imaging (MRI) Radio Frequency (RF) coil, comprising: an improved ELR material, wherein the RF coil is electrically coupled to an alternating

current source, wherein the RF coil induces an electromagnetic field during an MRI procedure in response to the alternating current source, the induced electromagnetic field causes certain atoms in a body of a subject to align and subsequently emit a resonance signal as the certain atoms become unaligned, wherein the resonance signal can be detected and used for imaging.

[00432] A magnetic resonance imaging (MRI) apparatus, comprising: an MRI magnet; an MRI RF coil, comprising: an improved ELR material, wherein during an MRI procedure the RF coil: induces a magnetic field when a current is applied to the at least one nanowire segment during an MRI procedure, wherein the electromagnetic field causes certain atoms in a body of a subject to align, or senses a resonance signal emitted by certain atoms in the body of the subject as certain aligned atoms become unaligned during the MRI procedure; a gradient coil, wherein the MRI gradient coil conducts an electrical current to generate a gradient field during an MRI procedure, wherein the gradient field causes certain atoms in a body of a subject to spin at different speeds based on a location in the body of the certain atoms; and an MRI detector that detects the sensed resonance signal from the MRI RF coil to generate an MRI image.

Chapter 5 - Capacitors formed of ELR Materials

[00433] This chapter of the description refers to Figures 1-36 and Figures 37A-B through Figure 43-B; accordingly all reference numbers included in this section refer to elements found in such figures.

[00434] Capacitors that include components formed of modified, apertured, and/or other new extremely low resistance (ELR) materials, are described. In some examples, the capacitors include one or more plates formed of ELR materials. In some examples, the capacitors include two plates or elements formed of ELR materials and a dielectric placed between the plates or elements. In some examples, the capacitors are formed using thin-film ELR materials. The ELR materials provide extremely low resistances to current at temperatures higher than temperatures normally associated with current high temperature superconductors (HTS), enhancing the operational characteristics of the capacitors at these higher temperatures, among other benefits.

[00435] In some examples, the ELR materials are manufactured based on the type of materials, the application of the ELR materials, the size of the component employing the ELR materials, the operational requirements of a device or machine employing the ELR materials, and so on. As such, during the design and manufacturing of a capacitor, the material used as a base layer of an ELR material and/or the material used as a modifying

layer of the ELR material may be selected based on various considerations and desired operating and/or manufacturing characteristics.

[00436] Various devices, applications, and/or systems may employ the ELR capacitors described herein. In some examples, tuned and other resonant circuits employ the ELR capacitors. In some examples, storage devices employ the ELR capacitors. In some examples, coupling elements employ the ELR capacitors. In some examples, pulsed power systems employ the ELR capacitors. In some examples, timing elements employ the ELR capacitors. In some examples, filtering elements employ the ELR capacitors.

[00437] As described herein, some or all of the modified, apertured, and/or other new ELR materials may be utilized by capacitors and associated devices and systems. Figure 37A-B is a schematic diagram illustrating a capacitor 3700 employing an ELR material. The capacitor includes a first plate 3710, or first conductive element, a second plate 3712, or second conductive element, and a space or gap 3715 that separates the first plate 3710 from the second plate 3712.

[00438] Applying a voltage or potential difference across the first plate 3710 and the second plate 3712 causes a static electric field to develop within the space 3715 between the two plates. The static electric field stores energy and produces a force between the plates. The "capacitance" of the capacitor, measured in Farads, is a ratio of the charge on each plate to the applied potential difference, or C=Q/V. The capacitance depends on the distance between the plates, and increases as the distance between the plates decreases.

[00439] Although the capacitor 3700 does not include a dielectric layer, many capacitors employ dielectric layers in order to increase their capacitance. Figure 37B-B is a schematic diagram illustrating a capacitor 3720 employing a modified ELR film. The capacitor 3720 includes a first plate 3730, a second plate 3732, and a dielectric, or non-conductive, layer 3735 located between the first plate 3730 and the second plate 3732. In some examples, the dielectric layer 3735 is formed of a material having a high permittivity and/or high breakdown voltage, in order to increase the amount of charge stored by the capacitor.

[00440] In some examples, the dielectric layer 3735 is an insulator. Example dielectric materials for use as dielectric layer 3735 include papers, plastics, glass, mica, ceramics, electrolytics, oxides, and/or other class 1 or class 2 dielectrics. The following listing represents various capacitor/dielectric types that may employ the modified, apertured,

and/or other new ELR materials described herein, although others are of course possible:

[00441] "air-gap" – capacitors with no dielectric layer, they generally have low dielectric loss. Air-gap capacitors may be employed as tunable capacitors for resonating HF antennas, among other implementations;

[00442] "ceramic" – capacitors having a ceramic dielectric layer, with varying permittivity values and dielectric losses. Examples include C0G, NP0, X7R, X8R, Z5U, and 2E6 capacitors. Ceramic capacitors may be employed by filters, timing elements, and crystal oscillators, among other implementations;

[00443] "glass" – capacitors having a glass dielectric layer, they are generally very stable and reliable;

[00444] "paper" – capacitors having a paper dielectric layer. Paper capacitors may be employed by radio equipment, power supplies, motors, and other implementations;

[00445] "polycarbonate" – capacitors having a polycarbonate dielectric layer, they generally have a low temperature coefficient and age well. Polycarbonate capacitors may be employed by filters, among other implementations;

[00446] "polyester" – capacitors having a PET film dielectric layer. Polyester capacitors may be employed by signal capacitors and integrators, among other implementations;

[00447] "polystyrene" - capacitors having a polystyrene dielectric layer. Polystyrene capacitors may be employed as signal capacitors, among other implementations;

[00448] "polypropylene" – capacitors having a polypropylene dielectric layer, they general exhibit low dielectric losses and high breakdown voltages. Polypropylene capacitors may be employed as signal capacitors, among other implementations;

[00449] "plastic" – capacitors having a plastic dielectric layer, they include PTFE or Teflon" dielectrics, among others;

[00450] "mica" – capacitors having a mica, such as a silvered mica, dielectric layer. Mica capacitors may be employed by HF and VHF RF circuits, among other implementations;

[00451] "electrolytic" – capacitors having an oxide dielectric layer surrounded by a dielectric solution, they generally have a larger capacitance per unit volume than other types. Electrolytic capacitors, which may be ultracapacitors and/or supercapacitors, may be employed in electrical circuits, as power-supply filters, coupling capacitors, energy storage devices, and other implementations;

[00452] "variable" – capacitors having a mechanical construction that changes the distance between the plates, or the amount of plate surface area which overlaps, and/or

variable capacitance (VARICAP) diodes that change their capacitance as a function of an applied reverse bias voltage. They may be employed by sensors, such as microphones, among other implementations;

[00453] "vacuum" – capacitors having a vacuum between conductive plates, they have no dielectric losses, self heal, and are variable and/or adjustable. They may be employed in high power RF transmitters, among other implementations; and other dielectric/capacitor types not specifically described herein.

[00454] In addition to capacitors formed of two plates separated by a dielectric layer, there are other ways in which to form capacitors. For example, metal conductive areas in different layers of a multi-layer printed circuit board or substrate may act as a highly stable capacitor. Additionally, a capacitor may be formed into various patterns of metallization on a substrate. Figure 37C-B is a schematic diagram illustrating a substrate-based capacitor 3740 employing ELR materials.

[00455] The capacitor 3740 is formed on a substrate 3745, and includes a first conductive element 3750 having various first conductive portions 3755, and a second conductive element 3760 having various second conductive portions 3765. As shown in the Figure, the capacitor 3740 may store charge within many electric fields produced between one of the first conductive portions 3755 and one of the second conductive portions 3765.

[00456] Figure 37D-B is a schematic diagram illustrating a MEMS type capacitor 3770 employing ELR materials. The capacitor 3770 is formed on or attached to a substrate (not shown), and includes a first conductive element 3780 having multiple first conductive portions 3782 and a second conductive element 3790 having multiple second conductive portions 3792 spaced apart from the multiple first conductive portions 3782. As shown in the Figure, the second conductive element 3790 may translationally move towards and/or away from the first conductive element 3780, increasing and/or decreasing a capacitance between the elements as the area between the respective conductive portions increases and/or decreases due to the movement. Additionally, the second conductive element 3790 may rotate with respect to the first conductive element 3780, increasing and/or decreasing a capacitance between the elements as the area between the respective conductive portions increases and/or decreases due to the rotation.

[00457] In some examples, the ELR materials described herein carry and/or propagate charge via apertures in the materials. Thus, in these examples, employing the ELR

materials as conductive elements may lead to a collection of charges within a conductive element, or plate, in discrete rows or sections, generally corresponding to the apertures within the materials.

[00458] Figure 38A-B is a cross-sectional view of the capacitor of Figure 37B-B taken at line BA. The capacitor 3800 includes a first conductive element 3810a having an apertured ELR material 3814a and a modifying layer 3812a bonded to the apertured ELR material 3814a, and a second conductive element 3810b having an apertured ELR material 3814b and a modifying layer 3812b bonded to the apertured ELR material 3814b. The first conductive element 3810a is separated form the second conductive element 3810b by a dielectric layer 3820.

[00459] After application of a potential difference between the first conductive element 3810a and the second conductive element 3810b, an electric field is produced between the elements and in the dielectric layer 3820, as charges 3830 move towards the dielectric layer 3820. However, because the charges are contained within apertures, they collect into groups of charges 3830 generally isolated from one another by walls 3835 of the apertures within the ELR material 3814a.

[00460] Figure 38B-B is a cross-sectional view of the capacitor of Figure 37B-B taken at line BB. The group charges may form strips of charges 3842 on or near a surface of the modifying layer 3840 or wall of the aperture, separated by the walls 3844 of the apertures of the material. Thus, the charges within the ELR material may, in response to an electric field within the capacitor, form strips and/or groupings of charges within the conductive elements of the capacitor.

[00461] In some examples, the ELR materials forming conductive elements of a capacitor may exhibit extremely low resistance to the flow of current at temperatures between the transition temperatures of conventional HTS materials (e.g. at ~80 to 135K) and room temperatures (e.g., at ~275K to 313K). In these examples, an ELR-based capacitor and/or ELR-based device employing a capacitor may include a cooling system (not shown), such as a cyrocooler or cryostat, used to cool the capacitor to a critical temperature for the type of modified ELR material utilized by the capacitor. For example, the cooling system may be a system capable of cooling the capacitor to a temperature similar to that of liquid Freon" , to a temperature similar to that of ice, or other temperatures discussed herein. That is, the cooling system may be selected based on the type and structure of the ELR materials utilized in the ELR-based capacitor and/or ELR-based device.

[00462] As described herein, in some examples, conductive elements (e.g., plates) of a capacitor exhibit extremely low resistances to carried current because it is formed of modified ELR materials. The conductive elements may be formed of a nanowire, a tape or foil, and/or a wire.

[00463] In forming an ELR wire, multiple ELR tapes or foils may be sandwiched together to form a macroscale wire. For example, a coil may include a supporting structure and one or more ELR tapes or foils supported by the supporting structure.

[00464] In addition to ELR wires, capacitors may be formed of ELR nanowires. In conventional terms, nanowires are nanostructures that have widths or diameters on the order of tens of nanometers or less and generally unstrained lengths. In some cases, the ELR materials may be formed into nanowires having a width and/or a depth of 50 nanometers. In some cases, the ELR materials may be formed into nanowires having a width and/or a depth of 40 nanometers. In some cases, the ELR materials may be formed into nanowires having a width and/or a depth of 30 nanometers. In some cases, the ELR materials may be formed into nanowires having a width and/or a depth of 20 nanometers. In some cases, the ELR materials may be formed into nanowires having a width and/or a depth of 10 nanometers. In some cases, the ELR materials may be formed into nanowires having a width and/or a depth of 5 nanometers. In some cases, the ELR materials may be formed into nanowires having a width and/or a depth less than 5 nanometers.

[00465] In addition to nanowires, ELR tapes or foils may also be utilized by the capacitors and devices described herein. There are various techniques for producing and manufacturing tapes and/or foils of ELR materials. In some examples, the technique includes depositing YBCO or another ELR material on flexible metal tapes coated with buffering metal oxides, forming a “coated conductor. During processing, texture may be introduced into the metal tape itself, such as by using a rolling-assisted, biaxially-textured substrates (RABiTS) process, or a textured ceramic buffer layer may instead be deposited, with the aid of an ion beam on an untextured alloy substrate, such as by using an ion beam assisted deposition (IBAD) process. The addition of the oxide layers prevents diffusion of the metal from the tape into the ELR materials. Other techniques may utilize chemical vapor deposition CVD processes, physical vapor deposition (PVD) processes, atomic layer-by-layer molecular beam epitaxy (ALL-MBE), and other solution deposition techniques to produce ELR materials.

[00466] Thus, the modified ELR films may formed into tapes, foils, rods, strips, nanowires, thin films, other shapes or structures, and/or other geometries capable of storing charge within conductive elements, such as plates. That is, while some suitable geometries are shown and described herein for some capacitors, numerous other geometries are possible. These other geometries include different patterns, configurations or layouts with respect to length and/or width, in addition to differences in thickness of materials, use of different layers, and other three – dimensional structures.

[00467] In some examples, the type of materials used as ELR materials may be determined by the type of application utilizing the ELR materials. For example, some applications may utilize ELR materials having a BSCCO ELR layer, whereas some applications may utilize a YBCO layer. That is, the ELR materials described herein may be formed into certain structures (e.g., tapes or nanowires) and formed from certain ELR materials, among other factors.

[00468] Various manufacturing processes may be employed when forming the ELR-based capacitors described herein. In some examples, an ELR nanowire conductive element is deposited onto a positioned substrate. In some examples, an ELR tape is placed or fixed onto a substrate, non-conductive element, and/or conductive element. One of ordinary skill will appreciate that other manufacturing processes may be utilized when manufacturing and/or forming the capacitors described herein.

[00469] As discussed herein, many devices and systems may utilize, employ and/or incorporate capacitors, such as modified, apertured, and/or other new ELR capacitors that exhibit extremely low resistances at high or ambient temperatures. The following section describes a few example devices, systems, and/or applications. One of ordinary skill will appreciate that other devices, systems, and/or applications may also utilize the modified ELR capacitors.

[00470] In some examples, a tuned or resonant circuit may employ the ELR-capacitors described herein. In general, a tuned circuit includes both a capacitor and inductor to select information in particular frequency bands. For example, a radio receiver relies on variable capacitors to tune the radio to a station frequency.

[00471] Figure 39-B is a schematic diagram illustrating a tuned or resonant circuit 3900 having an ELR capacitor 3910 and another component, such as an inductor 3920. Analog circuits, such as circuits used in signal processing applications, may utilize the capacitors described herein. These circuits may include a capacitor along with other components (e.g., LC circuits, RLC circuits, and so on). In some examples, the circuit

3900 may be a tuned or resonant circuit that emphasizes or filters out signal frequencies. In some examples, the circuit 3900 may remove residual hum in large-scale power applications. In some examples, the circuit 3900 may be a tuned circuit used in radio reception and broadcasting. One skilled in the art will appreciate that circuit 3900 may be implemented in many other applications not described herein.

[00472] In some examples, an energy storage component may employ the ELR-based capacitors described herein. For example, a capacitor stores electric energy when disconnected from a charging circuit, exhibiting similar characteristics to those batteries, and are often used in electronic devices to maintain power supplies while batteries are being changed, among other things.

[00473] Figure 40-B is a schematic diagram illustrating a storage element 4000 having an ELR capacitor. The storage element 4000 is representative of a supercapacitor, and includes a first electrode 4010, a second electrode 4020, and a separation layer. The separation layer 4030 separates a first electrolytic solution 4045 that contains charges 4040, and a second electrolytic solution 4055 containing charges 4050. Such a supercapacitor, employing the ELR-based materials described herein, may store energy for a variety of applications, such as electric vehicles and grid applications, among other things.

[00474] In some examples, a coupling component may employ the ELR-based capacitors described herein. For example, the ELR-based capacitor may facilitate capacitive coupling within a circuit, whereby the capacitor passes AC signals but blocks DC signals. As another example, the ELR-based capacitor may act as a decoupling capacitor that suppresses noise or transient signals between circuit elements.

[00475] Figure 41-B is a schematic diagram illustrating a coupling element 4100 having an ELR capacitor 4130 and a resistor 4140. The coupling element 4100 receives an input signal 4110, conditions the input based, in part on a time of charging a capacitor versus a time constant of the signal, and outputs a conditioned signal 4120. Such a coupling circuit, employing the ELR-based capacitors described herein, may pass audio signals in a radio system, among other things.

[00476] In some examples, a pulsed power system may employ the ELR-based capacitors described herein. For example, groups of large, specially constructed, low-inductance high-voltage capacitors may be used to supply large pulses of current for pulsed power applications, such as electromagnetic forming, Marx generators, pulsed

lasers, pulse forming networks, radar, fusion, particle accelerators, railguns, coilguns, and other applications.

[00477] Figure 42-B is a schematic diagram illustrating a pulsed power system 4200 having an ELR capacitor. The pulsed power system 4200 includes a capacitor bank 4100 formed of a number of capacitors 4220, which, when discharged, supply pulses of power to various output 4230 applications. For example, the system 4200 may be a Marx Bank, where capacitors, such as ELR-based capacitors, are charged in parallel with a moderate voltage, and discharged in series by triggering spark gaps that deliver a high voltage to the load. In some examples, a timing element may employ the ELR-based capacitors described herein.

[00478] Figure 43-B is a schematic diagram illustrating a timing element 4310, such as an element configured as an astable multivibrator 4310 delivering a pulse train via the ELR-based capacitor 4330 to a loudspeaker 4320. The timing element 4300 includes a 555 timer, an ELR-based capacitor 4330, and a loudspeaker 4320. The capacitor 4330 enables steady AC signaling to the loudspeaker while blocking DC signals, among other things.

[00479] Of course, other systems and devices may employ the ELR-based capacitors described herein. For example, power conditioning systems, power factor correction systems, noise filters, snubbers, motor starters, signal processors, sensors, measurement devices, touch input devices, human interface elements, neural networks, and so on.

[00480] In some implementations, a capacitor that includes modified ELR materials may be described as follows:

[00481] A capacitor, comprising: a first plate formed of a modified ELR material; and a second plate formed of a modified ELR material; wherein the modified ELR material includes a layer of ELR material and a modifying layer that modifies one or more operating characteristics of the layer of ELR material.

[00482] A method of forming a capacitor, the method comprising: forming a first plate of a modified ELR material; forming a second plate of the modified ELR material; and positioning the first plate a certain distance from the second plate.

[00483] A capacitor, comprising: a first modified extremely low resistance (ELR) element; and a second modified ELR element spaced a certain distance from the first modified ELR element.

[00484] A capacitor, comprising: a first plate formed of a modified ELR material; a second plate formed of a modified ELR material; and a dielectric positioned between the first plate and the second plate; wherein the modified ELR material includes a layer of ELR material and a modifying layer that modifies one or more operating characteristics of the layer of ELR material.

[00485] A method of forming a capacitor, the method comprising: forming a first plate of a modified ELR material; forming a second plate of the modified ELR material; positioning the first plate a certain distance from the second plate; and placing a dielectric between the first plate and the second plate.

[00486] A capacitor, comprising: a first modified extremely low resistance (ELR) element; a second modified ELR element spaced a certain distance from the first modified ELR element; and a dielectric material positioned between the first modified ELR element and the second modified ELR element.

[00487] A capacitor, comprising: a substrate; a first conductive element deposited onto the substrate and formed of a modified ELR material; a second conductive element deposited onto the substrate proximate to the first conductive element and formed of a modified ELR material; and wherein the modified ELR material includes a layer of ELR material and a modifying layer that modifies one or more operating characteristics of the layer of ELR material.

[00488] A method of forming a capacitor, the method comprising: depositing a first conductive element formed of a modified ELR material onto a substrate; and depositing a second conductive element formed of a modified ELR material proximate to the first conductive element onto the substrate.

[00489] A capacitor, comprising: a first modified extremely low resistance (ELR) element deposited onto a substrate; and a second modified ELR element deposited onto the substrate proximate to the first modified ELR element and spaced a certain distance from the first modified ELR element.

[00490] A capacitor, comprising: a first conductive element formed of a modified ELR material; a second conductive element formed of a modified ELR material and configured to move relative to the first conductive element; and wherein the modified ELR material includes a layer of ELR material and a modifying layer that modifies one or more operating characteristics of the layer of ELR material.

[00491] A capacitor, comprising: a first modified extremely low resistance (ELR) element; a second modified ELR element; and a positioning component, wherein the positioning

component is configured to move the second modified ELR element relative to the first modified ELR element.

[00492] A conductive element for use in a MEMS based capacitor, comprising: a first layer of ELR material; and a second layer of modifying material that modifies phonon characteristics of the ELR material.

[00493] A circuit, comprising: an inductor; and a capacitor, wherein the capacitor includes: a first conductive element formed of a modified ELR material; a second conductive element formed of a modified ELR material.

[00494] A capacitor for use in a signal processing device, comprising: a first conductive element formed of a modified ELR material; and a second conductive element formed of the modified ELR material; wherein the modified ELR material includes a layer of ELR material and a modifying layer that modifies one or more operating characteristics of the layer of ELR material.

[00495] A capacitor configured to exchange energy with an inductor in a circuit, comprising: a first conductive element formed on a substrate; and a second conductive element formed on the substrate and positioned proximate to the first conductive element; wherein the first conductive element and the second conductive element exhibit extremely low resistance to electrical charge at temperatures above 150K at standard pressure.

[00496] An ultracapacitor, comprising: a first conductive element formed of a modified ELR material; a second conductive element formed of a modified ELR material; a separating layer placed between the first conductive element and the second conductive element.

[00497] An ultracapacitor, comprising: a first conductive element formed of an apertured ELR material; a second conductive element formed of the apertured ELR material; a separating layer placed between the first conductive element and the second conductive element;

[00498] A coupling circuit, comprising: a resistor; and a capacitor, wherein the capacitor includes: a first conductive element formed of a modified ELR material; and a second conductive element formed of a modified ELR material; wherein the modified ELR material includes a layer of ELR material and a modifying layer that modifies one or more operating characteristics of the layer of ELR material.

[00499] A coupling circuit, comprising: a resistor; and a capacitor, wherein the capacitor includes: a first conductive element formed of an apertured ELR material; and a second

conductive element formed of the apertured ELR material; wherein the apertured ELR material includes a layer of ELR material and a modifying layer that modifies one or more operating characteristics of the layer of ELR material.

[00500] A pulsed power system, comprising: a capacitor bank, wherein each of the capacitors within the capacitor bank includes: a first conductive element formed of a modified ELR material; and a second conductive element formed of a modified ELR material; wherein the modified ELR material includes a layer of ELR material and a modifying layer that modifies one or more operating characteristics of the layer of ELR material.

[00501] A pulsed power system, comprising: a capacitor bank, wherein each of the capacitors within the capacitor bank includes: a first conductive element formed of an ELR material; and a second conductive element formed of an ELR material; wherein the ELR material includes a layer of apertured ELR material and a modifying layer that modifies one or more operating characteristics of the layer of apertured ELR material.

[00502] A sensor, comprising: a capacitor, wherein the capacitor includes: a first conductive element formed of a modified ELR material; and a second conductive element formed of a modified ELR material; wherein the modified ELR material includes a layer of ELR material and a modifying layer that modifies one or more operating characteristics of the layer of ELR material.

[00503] A sensor, comprising: a capacitor, wherein the capacitor includes: a first conductive element formed of an ELR material; and a second conductive element formed of an ELR material; wherein the ELR material includes a layer of apertured ELR material and a modifying layer that modifies one or more operating characteristics of the layer of apertured ELR material.

Chapter 6 - Inductors formed of ELR Materials

[00504] This chapter of the description refers to Figures 1-36 and Figures 37-C through Figure 43-C; accordingly all reference numbers included in this section refer to elements found in such figures.

[00505] Inductors, such as air core or magnetic core inductors, that include components formed of extremely low resistance (ELR) materials, such as modified ELR materials, apertured ELR materials, and/or other new ELR materials, are described. In some examples, the inductors include a core and a nanowire coil formed of ELR materials. In some examples, the inductors include a core and coil formed of ELR materials, such as ELR tapes or foils. In some examples, the inductors are formed using thin-film ELR

materials. The ELR materials provide and/or exhibit extremely low resistances to current at temperatures higher than temperatures normally associated with conventional high temperature superconductors (HTS), enhancing the operational characteristics of inductors at these higher temperatures, among other benefits.

[00506] In some examples, the ELR materials are manufactured based on the type of materials, the application of the ELR materials, the size of the component employing the ELR materials, the operational requirements of a device, system, and/or machine employing the ELR materials, and so on. As such, during the design and manufacturing of an inductor or inductor-based device, the material used as a base layer of an ELR component and/or the material used as a modifying layer of an ELR component may be selected based on various considerations and desired operating and/or manufacturing characteristics.

[00507] Various devices, applications, and/or systems may employ the modified, apertured, and/or new ELR-based inductors. In some examples, tuned or resonant circuits and associated applications employ ELR inductors. In some examples, transformers and associated applications employ ELR inductors. In some examples, energy storage devices and associated applications employ ELR inductors. In some examples, current limiting devices, such as fault current limiters, and associated applications employ ELR inductors.

[00508] Figure 37-C is a schematic diagram illustrating an air core inductor 3700 formed of modified, apertured, and/or new ELR materials. The inductor 3700 includes a coil 3710 and an air core 3720. When the coil 3710 carries a current (e.g., in a direction towards the right of the page), a magnetic field 3730 is produced in the air core 3720 (that is, in the area where a core would be found). The coil is formed, at least in part, of ELR materials, such as an ELR film having a ELR material base layer and a modifying layer formed on the base layer. Various suitable ELR films are described in detail herein.

[00509] A battery or other power source (not shown) may apply a voltage to the ELR coil 3710, causing current to flow within the coil 3710. Being formed of ELR materials, the coil 3710 provides little or no resistance to the flow of current in at temperatures higher than those used in conventional HTS materials, such as room or ambient temperatures (e.g., at ~21 degrees C). The current flow in the coil produces a magnetic field within the core area 3720, which may be used to transfer energy, limit energy, and so on.

[00510] Because the inductor 3700 includes a coil 3710 formed of extremely low resistance materials (i.e. a modified ELR film), the inductor may act similarly to an ideal

inductor, where the coil 3710 exhibits little or no losses due to winding or series resistance typically found in inductors with conventional conductive coils (e.g., copper coils), regardless of the current through the coil 3710. That is, the inductor 3700 may exhibit a very high quality (Q) factor (e.g., approaching infinity), which is the ratio of its inductive reactance to resistance at a given frequency, or Q = (inductive reactance)/resistance.

[00511] In some examples, the ELR coil provides extremely low resistance to the flow of current at temperatures between the transition temperatures of conventional HTS materials (e.g., at ~80 to 135K) and room temperatures (e.g., at ~294K). In these examples, the inductor may include a cooling system (not shown), such as a cyrocooler or cryostat, used to cool the coil 3710 to a critical temperature for the type of ELR materials utilized by the coil 3710. For example, the cooling system may be a system capable of cooling the coil 3710 to a temperature similar to that of liquid Freon^{TM}, to a temperature similar to that of ice, or to other temperatures discussed herein. That is, the cooling system may be selected based on the type and structure of the ELR materials utilized in the coil 3710.

[00512] In some examples, the air core 3720 does not include any additional material, and the inductor 3700 is a coil without a physical core, such as a stand-alone coil (e.g., the coil shown in the Figure). In some examples, the air core 3720 is formed of a non-magnetic material (not shown), such as plastic or ceramic materials. The material or shape of the core may be selected based on a variety of factors. For example, selecting a core material having a higher permeability than the permeability of air will generally increase the density of the produced magnetic field 3730, and thus increase the inductance of the inductor 3700. In another example, selecting a core material may be governed by a desire to reduce core losses within high frequency applications. One skilled in the art will appreciate the core may be formed of a number of different materials and into a number of different shapes in order to achieve certain desired properties and/or operating characteristics.

[00513] As is known in the art, the configuration of the coil 3710 may affect certain operational characteristics, such as the inductance. For example, the number of turns of a coil, the cross-sectional area of a coil, the length of a coil, and so on, may affect the inductance of an inductor. It follows that inductor 3700, although shown in one configuration, may be configured in a variety of ways in order to achieve certain

operational characteristics (e.g., inductance values), to reduce certain undesirable effects (e.g. skin effects, proximity effects, parasitic capacitances), and so on.

[00514] In some examples, the coil 3710 may include many turns lying parallel to one another. In some examples, the coil may include few turns that are wound at different angles to one another. Thus, coil 3710 may be formed into a variety of different configurations, such as honeycomb, basket-weave patterns, wave windings where successive turns criss-cross at various angles to one another, spiderweb patterns or pi windings, where the coil is formed of flat spiral coils spaced apart from one another, as litz wires, where various strands are insulated from one another to reduce arc resistance, and so on. These techniques may be adopted to increase the self-resonant frequency and quality factor (Q) of an inductor, among other benefits.

[00515] In addition to air core inductors, magnetic core inductors, such as inductor 3800, may also utilize the modified, apertured, and/or new ELR materials discussed herein. Figure 38-C is a schematic diagram illustrating a magnetic core inductor 3800 employing ELR materials. The inductor 3800 includes a coil 3810 and a magnetic core 3820, such as a core formed of ferromagnetic or ferromagnetic materials. Similar to the inductor 3700 of Figure 37-C, a magnetic field 3830 is produced in the core 3820 when current is carried by the coil 3810. The coil is formed, at least in part, of an ELR film, such as a film having a ELR material base layer and a modifying layer formed on the base layer. Various suitable ELR films are described in detail herein. Being formed of an ELR film, the coil 3810 provides little or no resistance to the flow of current in at temperatures higher than those used in conventional HTS materials, such as room or ambient temperatures (e.g., at ~21 degrees C). The current flow in the coil produces a magnetic field 3830 within the core 3820, which may be used to store energy, transfer energy, limit energy, and so on.

[00516] The magnetic core 3820, being formed of ferromagnetic or ferromagnetic materials, increases the inductance of the inductor 3800 because the magnetic permeability of the magnetic material within the produced magnetic field 3830 is higher than the permeability of air, and thus is more supportive of the formation of the magnetic field 3830 due to the magnetization of the magnetic material. For example, a magnetic core may increase the inductance by a factor of 1,000 times or greater.

[00517] The inductor 3800 may utilize various different materials within the magnetic core 3820. In some examples, the magnetic core 3820 is formed of a ferromagnetic material, such as iron. In some examples, the magnetic core 3820 is formed of a

ferromagnetic material, such as ferrite. In some examples, the magnetic core 3820 is formed of laminated magnetic materials, such as silicon steel laminations, metglas, or other materials. One of ordinary skill will appreciate that other materials may be used, depending on the needs and requirements of the inductor 3800.

[00518] In addition, the magnetic core 3820 (and, thus, the inductor 3800) may be configured into a variety of different shapes. In some examples, the magnetic core 3820 may be a rod or cylinder. In some cases, the magnetic core 3820 may be a donut or toroid. In some cases, the magnetic core 3820 may be moveable, enabling the inductor 3800 to realize variable inductances. One of ordinary skill will appreciate that other shapes and configurations may be used, depending on the needs and requirements of the inductor 3800. For example, the magnetic core 3820 may be constructed to limit various drawbacks, such as core losses due to eddy currents and/or hysteresis, and/or nonlinearity of the inductance, among other things.

[00519] Thus, in some examples, forming the coil 3710 of the inductor 3700 or the coil 3810 of the inductor 3800 using modified ELR materials and/or components, such as modified ELR films, increases the Q factor of the inductors by lowering or eliminating the resistance to current within the coils, among other benefits.

[00520] As described herein, in some examples, a coil of an inductor exhibits extremely low resistances to carried current because it is formed of ELR materials, such as modified ELR materials, apertured ELR materials, new ELR materials, and so on. Figure 39A-C is a schematic diagram illustrating an inductor 3900 employing an ELR wire. The inductor 3900 includes a coil 3902 formed as an ELR wire that is composed of the ELR components described herein, such as modified ELR films.

[00521] In forming an ELR wire, multiple ELR tapes or foils may be sandwiched together to form a macroscale wire. For example, a coil may include a supporting structure and one or more ELR tapes or foils supported by the supporting structure.

[00522] In addition to ELR wires, inductors may be formed of ELR nanowires. In conventional terms, nanowires are nanostructures that have widths or diameters on the order of tens of nanometers or less and generally unstrained lengths. In some cases, the ELR materials may be formed into nanowires having a width and/or a depth of 50 nanometers. In some cases, the ELR materials may be formed into nanowires having a width and/or a depth of 40 nanometers. In some cases, the ELR materials may be formed into nanowires having a width and/or a depth of 30 nanometers. In some cases, the ELR materials may be formed into nanowires having a width and/or a depth of 20

nanometers. In some cases, the ELR materials may be formed into nanowires having a width and/or a depth of 10 nanometers. In some cases, the ELR materials may be formed into nanowires having a width and/or a depth of 5 nanometers. In some cases, the ELR materials may be formed into nanowires having a width and/or a depth less than 5 nanometers.

[00523] In addition to nanowires, ELR tapes or foils may also be utilized by the inductors and devices described herein. Figure 39B-C is a schematic diagram illustrating an inductor 3910 employing an ELR tape or foil. The inductor 3910 includes a core 3912, such as an iron core, and a coil 3914 formed of an ELR tape.

[00524] There are various techniques for producing and manufacturing tapes and/or foils of ELR materials. In some examples, the technique includes depositing YBCO or another ELR material on flexible metal tapes coated with buffering metal oxides, forming a "coated conductor. During processing, texture may be introduced into the metal tape itself, such as by using a rolling-assisted, biaxially-textured substrates (RABiTS) process, or a textured ceramic buffer layer may instead be deposited, with the aid of an ion beam on an untextured alloy substrate, such as by using an ion beam assisted deposition (IBAD) process. The addition of the oxide layers prevents diffusion of the metal from the tape into the ELR materials. Other techniques may utilize chemical vapor deposition CVD processes, physical vapor deposition (PVD) processes, atomic layer-by-layer molecular beam epitaxy (ALL-MBE), and other solution deposition techniques to produce ELR materials.

[00525] In some examples, thin film inductors may utilize the ELR components described herein. Figure 39C-C is a schematic diagram illustrating an inductor 3920 employing an ELR thin film component, such as a modified, apertured, and/or new ELR component. The inductor 3920 includes an ELR coil 3922 formed onto a printed circuit board 3924 or other suitable substrate (e.g., LaSrGaO), and an optional magnetic core 3926. The coil 3922, which may be a modified ELR film etched into the board 3924 or substrate, or a nanowire located on or at a substrate, may be formed in a variety of configurations and/or patterns, depending on the needs of the device or system employing the inductor. Further, the optional magnetic core 3926 may be etched into the board 3924, as shown, or may be a planar core (not shown) positioned above and/or below the coil 3922.

[00526] Thus, the ELR materials may formed into wires, tapes, foils, rods, strips, nanowires, thin films, other coiled/spiral shapes, structures, and/or geometries capable

of moving or carrying current from one point to another in order to produce a magnetic field. That is, while some suitable geometries are shown and described herein for some inductors, numerous other geometries are possible. These other geometries include different patterns, configurations or layouts with respect to length and/or width, in addition to differences in thickness of materials, use of different layers, and other three – dimensional structures.

[00527] In some examples, the type of materials used in the ELR materials may be determined by the type of application utilizing the ELR materials. For example, some applications may utilize a BSCCO ELR layer, whereas other applications may utilize a YBCO ELR layer. That is, the ELR materials described herein may be formed into certain structures (e.g., wires, tapes, foils, thin films, and/or nanowires) and formed from certain materials (e.g., YBCO or BSCCO) based on the type of machine or component utilizing the ELR materials, among other factors.

[00528] Various processes may be employed in manufacturing an inductor, such as inductors 3900, 3910, and/or 3920. In some examples, a core is formed, maintained, fixed, received and/or positioned. The core may take on various shapes or configurations. Example configurations include a cylindrical rod, a single "I" shape, a "C" or "U" shape, an "E" shape, a pair of "E" shapes, a pot-shape, a toroidal shape, a ring or bead shape, a planar shape, and so on. The core may be formed of various non-magnetic and magnetic materials. Example materials include iron or soft iron, silicon steel, various laminated materials, alloys of silicon, carbonyl iron, iron powders, ferrite ceramics, vitreous or amorphous metals, ceramics, plastics, metglas, air, and so on.

[00529] In addition, a coil, such as a coil formed of an ELR nanowire, tape, or thin film, is configured into a desirable shape or pattern and coupled to the formed or maintained core. In some examples, there is no core, and the modified ELR nanowire is configured to the desirable shape or pattern. In some examples, a modified ELR nanowire coil is etched directly on a printed circuit board or formed or etched into an integrated circuit, and a planar magnetic core is positioned with respect to the etched coil. One of ordinary skill will appreciate that other manufacturing processes may be utilized when manufacturing and/or forming the inductors described herein.

[00530] As discussed herein, many devices and systems may utilize, employ and/or incorporate inductors, such as modified, apertured, and/or new ELR inductors that exhibit extremely low resistances at high or ambient temperatures, such as temperatures between 150K to 313K, or higher than 313K. That is, virtually any device or system that

utilizes energy stored in a magnetic field produced from an electric current may incorporate the ELR inductors described herein. For example, systems that transfer, transform and/or store energy, information and/or objects may employ the ELR inductors described herein. The following section describes a few example devices, systems, and/or applications. One of ordinary skill will appreciate that other devices, systems, and/or applications may also utilize the ELR inductors described herein.

[00531] In some examples, analog circuits, such as circuits used in signal processing applications, may utilize the inductors described herein. Figure 40-C is a schematic diagram illustrating a tuned or resonant circuit 4000 having an ELR-based inductor 4010, and a capacitor 4020. Such circuits may include an inductor along with other components (e.g., LC circuits, RLC circuits, and so on). In some examples, the circuit 4000 may be a tuned or resonant circuit that amplifies and/or attenuates signal frequencies. In some examples, the circuit 4000 may be remove residual hums (e.g. by filtering out 60 Hz signals and associated harmonics) in large-scale power applications. In some examples, the circuit 4000 may be a tuned circuit used in radio reception and broadcasting. One skilled in the art will appreciate that circuit 4000 may be implemented in many other applications not described herein.

[00532] Utilization of extremely low resistance materials, such as the modified ELR materials described herein, may provide a variety of advantages and benefits to circuit 4000. For example, a circuit having ELR inductors utilized in a magnetometer (e.g., a SQUID) may enable the magnetometer to measure extremely small magnetic fields (e.g., on the order of one fluxon), among other benefits, without the reliance on expensive cooling systems typical of magnetometers employing conventional HTS superconducting elements.

[00533] In some examples, transformers and other energy transfer devices and systems may utilize the inductors described herein. Figure 41-C is a schematic diagram illustrating a transformer 4100 having an ELR inductor. The transformer 4100 includes a magnetic core 4110, a primary winding 4120 having primary winding turns 4125, and a secondary winding 4130 having secondary winding turns 4135. The primary winding 4120 and the secondary winding 4130 are formed of the ELR materials, such as modified ELR nanowires. In some examples, the transformer 4100 may be part of a utility power grid. In some examples, the transformer 4100 may be part of appliances and other electronic devices that step up and/or step down supply voltages during operation. In some examples, the transformer 4100 may be a signal or audio transformer.

One skilled in the art will appreciate that the transformer 4100 may be implemented in many other applications and devices not described herein.

[00534] Utilization of extremely low resistance materials, such as the modified ELR materials described herein, may provide a variety of advantages and benefits to the transformer 4100 and/or various applications. For example, transformers utilizing modified ELR materials within coils exhibit fewer resistive losses, which can greatly affect the cost of operation by minimizing energy losses within the transformer, among other benefits, while avoiding the problems associated with conventional superconducting materials, such as high costs due to expensive cooling systems, among other things.

[00535] In some examples, energy storage devices, such as superconducting magnetic energy storage (SMES) systems and other magnetic storage systems, may utilize the ELR inductors described herein. Figure 42-C is a schematic diagram illustrating an energy storage system 4200 having an ELR inductor. The energy storage system 4200 includes a storage component 4210 having an inductor coil 4215 or coils and a power conditioning system 4220 having an inverter-rectifier 4225. The storage component 4210 stores energy in magnetic fields produced by inductors 4215 formed of modified ELR materials. The power conditioning system 4220 may receive energy from the storage component 4210, condition the received energy (e.g., convert stored DC current to AC current), and supply the conditioned energy to various sources, such as a power installation 4230. One skilled in the art will appreciate that the energy storage system 4200 may be implemented in many other applications and devices not described herein.

[00536] Utilization of extremely low resistance materials, such as the modified ELR materials described herein, may provide a variety of advantages and benefits to the energy storage system 4200 and various applications. For example, conventional SMES systems lose the least amount of stored energy as compared to other energy storage systems, but costs and other problems associated with maintaining high temperature superconductors in the conventional SMES systems at temperatures of the order of liquid nitrogen have prohibited their widespread adoption, among other problems. On the other hand, the modified ELR inductors described herein provide similar benefits to the conventional SMES systems (e.g., few energy losses), without the problems (e.g., costs of cryocoolers) associated with conventional SMES systems, because they exhibit ELR properties at very high temperatures, such as anywhere between the temperature of liquid Freon to room temperatures, or higher.

[00537] In some examples, electrical transmission systems may utilize the ELR materials described herein. Figure 43-C is a schematic diagram illustrating a current limiting system 4300, such as a fault current limiter (FCL), having an ELR inductor. The current limiting system includes a current limiter 4310 composed of an ELR inductor 4315. The current limiter 4310, such as a series resistive limiter, is positioned between a line 4320 and a load 4330 and acts as a trigger coil by shunting a fault to resistor 4330, absorbing most of the energy during a fault on the system 4300. One skilled in the art will appreciate that an electrical transmission system may implement ELR inductors in many other applications and devices not specifically described in Figure 43-C.

[00538] Utilization of extremely low resistance materials, such as the modified, apertured, and/or new ELR materials described herein, may provide a variety of advantages and benefits to electrical transmission systems and various applications. For example, ELR inductors may function to limit fault currents in a system during fault states without adding impedance to the system during normal operation states, because they exhibit extremely low resistance to current within the system, among other benefits.

[00539] In some examples, some or all of the systems and devices describes herein may employ low cost cooling systems in applications where the specific ELR materials utilized by the application exhibit extremely low resistances at temperatures lower than ambient temperatures. As discussed herein, in these examples the application may include a cooling system (not shown), such as a system that cools an ELR inductor to a temperature similar to that of liquid Freon, to a temperature similar to that of ice, or other temperatures discussed herein. The cooling system may be selected based on the type and structure of the ELR materials utilized by the applications and/or the inductors employed by the applications.

[00540] In addition to the systems, devices, and/or applications described herein, one skilled in the art will realize that other systems, devices, and application that include inductors may utilize the modified, apertured, and/or new ELR inductors described herein.

[00541] In some implementations, an inductor that includes modified ELR materials may be described as follows:

[00542] An inductor, comprising: an air core; and a modified extremely low resistance (ELR) element configured into a coil shape at least partially surrounding the air core; wherein the modified ELR element is formed of a modified ELR film having a first layer

comprised of an ELR material and a second layer comprised of a modifying material bonded to the ELR material of the first layer.

[00543] An apparatus, comprising: a substrate; a coil embedded in the substrate; and a first magnetic core positioned above the surface of the substrate; and a cooling component configure to maintain the coil embedded in the substrate at a temperature lower than a surrounding temperature of the substrate; wherein the coil includes a first portion having an extremely low resistance (ELR) material and a second portion bonded to the first portion that lowers the resistance of the ELR material.

[00544] An apparatus, comprising: a magnetic core; and a three dimensional coil wrapped at least partially around the magnetic core; wherein the three dimensional coil includes a first portion having an extremely low resistance (ELR) material and a second portion bonded to the first portion that lowers the resistance of the ELR material.

[00545] An inductor configured to be placed between a load and a line, the inductor comprising: a modified ELR material having a first layer formed of an ELR material and a second layer formed of a material that modifies the resistance of the ELR material; wherein the inductor is configured to not resist current at normal load levels traveling through the inductor and resist current at fault load levels traveling through the inductor.

[00546] An energy storage system, comprising: a storage component, wherein the storage component includes an inductor formed of a modified ELR film and is configured to store energy in a magnetic field produced by the inductor; a power conditioning component, wherein the power conditioning component is configured to condition energy received from the storage component; and a power supply component, wherein the power supply component is configured to supply the conditioned energy to a recipient.

[00547] An inductor, comprising: a substrate; and a modified extremely low resistance (ELR) film formed on a surface of the substrate; wherein the modified ELR film includes a first layer comprised of an ELR material and a second layer comprised of a modifying material bonded to the ELR material of the first layer.

[00548] A transformer, comprising: a primary, wherein the primary includes: a first magnetic core; a first modified extremely low resistance (ELR) element configured into a coil shape having a first number of turns and at least partially surrounding the magnetic core; and a secondary, wherein the secondary includes: a second magnetic core; a second modified extremely low resistance (ELR) element configured into a coil shape having a second number of turns and at least partially surrounding the magnetic core; wherein the first and second modified ELR elements are formed of a modified ELR film

having a first layer comprised of an ELR material and a second layer comprised of a modifying material bonded to the ELR material of the first layer.

[00549] An inductor for use in a signal processing device, comprising: a magnetic core; and a three dimensional coil wrapped at least partially around the magnetic core; wherein the three dimensional coil includes a first portion having an extremely low resistance (ELR) material and a second portion bonded to the first portion that lowers the resistance of the ELR material.

Chapter 7 – Transistors Formed of ELR Materials

[00550] This chapter of the description refers to Figures 1-36 and Figures 37-D through Figure 44-D; accordingly all reference numbers included in this section refer to elements found in such figures.

[00551] Transistors and other similar devices, such as logic devices, that include components formed of modified extremely low resistance (ELR) and/or apertured ELR materials are described. As is discussed herein, modified and/or apertured ELR materials exhibit extremely low resistance to electric charge (e.g., the flow of electrons) and/or extremely high conductance of electric charge at high temperatures, such as temperatures above 150K, at ambient or standard pressures.

[00552] In some examples, the devices include a junction formed of a semiconducting element and an ELR element. For example, devices that may utilize such an ELR element-semiconductor junction include Josephson junctions, bipolar junction transistors, field effect transistors (FETs), amplifiers, switches, logic gates, microprocessor elements, microprocessors, and so on.

[00553] In some examples, the ELR materials are manufactured based on the type of materials, the application of the modified ELR material, the size of a component and/or device employing the ELR material, the operational requirements of a component and/or device employing the ELR material, and so on. For example, during the design and manufacturing of a transistor, the material used as a base layer of an ELR material-based electrode and/or the material used as a modifying layer of the ELR material-based electrode may be selected based on various considerations and desired operating and/or manufacturing characteristics.

[00554] Thus, in some examples, devices that employ ELR material-semiconductor junctions may perform faster and more reliably with respect to conventional devices, because conductive elements within the devices do not resist the flow of current, among

other things. Furthermore, devices may be designed with fewer elements, which may lower costs associated with manufacturing, among other things.

[00555] As described herein, some or all of the modified, apertured, and/or other new ELR materials may be utilized by transistors and associated devices and systems that employ junctions, such as junctions formed of at least one conductive element and at least one semiconductor.

[00556] Figure 37-D is a schematic diagram illustrating a junction between an extremely low resistance (ELR) element and a semiconductor. The junction 3700 includes an ELR-based element 3710 and a semiconductor 3720. The semiconductor 3720 may be formed of a variety of different known semiconducting materials, such as silicon, gallium arsenide (GaAs), and so on.

[00557] In some examples, a device 3705 may employ the junction 3700. The ELR material-semiconductor junction 3700 may combine ELR-based electronics and semiconducting electronics. For example, the junction 3700 may act to combine Rapid Single Flux Logic (RSFL) circuits to semiconducting circuits. That is, the junction 3700 may be part of a Josephson Field Effect Transistor (JoFET) or other transistors that rely on the Josephson effect, whereby electric current flows between two weakly coupled ELR elements.

[00558] Figure 38-D is a schematic diagram illustrating a Josephson junction 3800 employing one or more ELR elements. The Josephson junction 3800 includes a first ELR element 3810 coupled to a second ELR element 3830 by a semiconductor 3820. The relative size of elements may vary according to application. That is, in some cases, the semiconductor 3820 may be formed of a smaller thickness or other geometry with respect to the ELR element 3810 and/or ELR element 3830. Furthermore, the ELR element 3810 may be formed of a certain thickness or other geometry that is different than a thickness and/or other geometry of the semiconductor 3820 and/or ELR element 3830.

[00559] Because the Josephson junction 3800 employs a semiconductor 3830 as the "insulator" between the first ELR element 3810 and the second ELR element 3830, the junction may act as a single-electron transistor, which can perform precise measurements because switching events at the junction are associated with the measurement of single fluxons, among other things.

[00560] For example, the Josephson junction 3800 may be used in Rapid Single Flux Quantum (RSFQ) components as qubits, in Superconducting Tunnel Junction (STJ) Detectors as detection components, and/or other applications.

[00561] In some examples, the ELR materials within the junctions 3700, 3800 may exhibit extremely low resistance to the flow of current at temperatures between the transition temperatures of conventional HTS materials (e.g., ~80 to 135K) and ambient temperatures (e.g., ~275K to 313K), such as between 150K and 313K, or higher. In these examples, an ELR element and/or ELR-based device employing the ELR element may utilize a cooling system (not shown), such as a cyrocooler or cryostat, used to cool the ELR element to a critical temperature for the type of modified ELR material utilized by the device. For example, the cooling system may be a system capable of cooling the ELR element to a temperature similar to that of the boiling point of Freon" , to a temperature similar to that of the melting point of water, to a temperature lower than what is ambient or surrounding the ELR element or associated device, or other temperatures discussed herein. That is, the cooling system may be selected based on the type and structure of the ELR material utilized in the ELR element and/or ELR-based device.

[00562] As described herein, in some examples, the conductive elements formed of ELR materials within ELR-based junction devices exhibit extremely low resistances to electric charge. These conductive elements may be formed of nanowires, tapes or foils, wires, and so on.

[00563] There are various techniques for producing and manufacturing tapes and/or foils of ELR materials. In some examples, the technique includes depositing YBCO or another ELR material on flexible metal tapes coated with buffering metal oxides, forming a “coated conductor. During processing, texture may be introduced into the metal tape itself, such as by using a rolling-assisted, biaxially-textured substrates (RABiTS) process, or a textured ceramic buffer layer may instead be deposited, with the aid of an ion beam on an untextured alloy substrate, such as by using an ion beam assisted deposition (IBAD) process. The addition of the oxide layers prevents diffusion of the metal from the tape into the ELR materials. Other techniques may utilize chemical vapor deposition CVD processes, physical vapor deposition (PVD) processes, atomic layer-by-layer molecular beam epitaxy (ALL-MBE), and other solution deposition techniques to produce ELR materials. In forming a wire, multiple modified ELR films may be sandwiched together to form the wire.

[00564] In forming an ELR wire, multiple ELR tapes or foils may be sandwiched together to form a macroscale wire. For example, an electrode may include one or more ELR tapes or foils.

[00565] In addition to ELR wires, electrodes and other conductive elements may be formed of ELR nanowires. In conventional terms, nanowires are nanostructures that have widths or diameters on the order of tens of nanometers or less and generally unstrained lengths. In some cases, the ELR materials may be formed into nanowires having a width and/or a depth of 50 nanometers. In some cases, the ELR materials may be formed into nanowires having a width and/or a depth of 40 nanometers. In some cases, the ELR materials may be formed into nanowires having a width and/or a depth of 30 nanometers. In some cases, the ELR materials may be formed into nanowires having a width and/or a depth of 20 nanometers. In some cases, the ELR materials may be formed into nanowires having a width and/or a depth of 10 nanometers. In some cases, the ELR materials may be formed into nanowires having a width and/or a depth of 5 nanometers. In some cases, the ELR materials may be formed into nanowires having a width and/or a depth less than 5 nanometers.

[00566] Thus, the modified ELR materials may formed into tapes, foils, rods, strips, nanowires, thin films, and other shapes or structures capable of moving or carrying current from one point or location to another point or location.

[00567] In some examples, the type of materials used in the ELR materials may be determined by the type of application utilizing the ELR materials. For example, some applications may utilize ELR materials having a BSCCO ELR layer, whereas some applications may utilize a YBCO ELR layer. That is, the ELR materials described herein may be formed into certain structures (e.g., tapes or nanowires) and formed from certain materials (e.g., YBCO or BSCCO) based on the type of device or component utilizing the ELR materials, among other factors.

[00568] Various manufacturing processes may be employed when forming the ELR-based junction devices described herein. For example, a first layer of ELR material may be deposited onto a substrate (such as a semiconducting substrate), followed by a second layer of modifying materials deposited onto the first layer. A semiconducting element may be placed proximate to the ELR materials, forming a junction. Of course, one or ordinary skill in the art will realize other processes may be utilized.

[00569] As discussed herein, many devices and systems may utilize, employ and/or incorporate the ELR-based junctions, such as transistors that include components that

exhibit extremely low resistances to current at high or ambient temperatures. The following section describes a few example devices, systems, and/or applications. One of ordinary skill will appreciate that other devices, systems, and/or applications may also utilize the ELR-based junctions.

[00570] Figure 39-D is a schematic diagram illustrating a transistor 3900 employing a semiconducting nanowire and one or more ELR elements. The transistor 3900 includes a nanowire 3910 formed of a semiconducting material, a first ELR element 3920, and a second ELR element 3925. In some cases, the ELR elements 3920, 3925 are also nanowires or other similarly sized elements.

[00571] In operation, a supercurrent (that is, a current flowing without resistance) within the first ELR element 3920 travels through the nanowire 3910 to the second ELR element 3925. Application of a gate voltage on the nanowire, such as by a gate electrode possibly formed of ELR materials, may control the current as it travels through the semiconducting nanowire 3910.

[00572] Small circuits may, therefore, utilize multiple transistors 3900, such as an array of transistors 3900. For example, a superconducting quantum interference device (SQUID) may be formed of two of such transistors 3900, and may be employed as a switchable coupling element between quantum bits (qubits), among other applications.

[00573] Figures 40A-D and 40B-D are schematic diagrams illustrating bipolar junctions transistors employing one or more ELR elements. Figure 40A-D depicts an npn bipolar junction transistor 4000. The npn bipolar junction transistor 4000 includes an emitter electrode 4010, a collector electrode 4012, and a gate electrode 4014, some or all of which are formed of ELR material, such as the modified and/or apertured ELR materials described herein. Between the emitter electrode 4010 and the collector electrode 4012 is an npn junction formed of a first n-type semiconductor 4020, a p-type semiconductor 4024, and a second n-type semiconductor 4022.

[00574] Figure 40B-D depicts a pnp bipolar junction transistor 4030. The pnp bipolar junction transistor 4030 includes an emitter electrode 4040, a collector electrode 4042, and a gate electrode 4044, some or all of which are formed of ELR material, such as the modified and/or apertured ELR materials described herein. Between the emitter electrode 4040 and the collector electrode 4042 is an npn junction formed of a first n-type semiconductor 4050, a p-type semiconductor 4054, and a second n-type semiconductor 4052.

[00575] In some examples, the npn bipolar junction transistor 4000 and/or the pnp bipolar junction transistor 4030 act as current regulating devices that control an amount of current flowing through the junction with respect to an amount of biasing voltage applied to their base terminal, such as a current-controlled switch. Because they are three terminal devices, they may affect input signals in three different ways: (1) providing a gain in voltage without a gain in current when in a common base configuration, (2) providing a gain in voltage and current when in a common emitter configuration, and (3) providing a gain in current without a gain in voltage in a common collector configuration. For example, the npn bipolar transistor 4000 may be employed as an amplifier when configured in the common emitter configuration.

[00576] Figure 41-D is a schematic diagram illustrating a field effect transistor (FET), such as a metal oxide semiconducting field effect transistor (MOSFET), employing one or more ELR elements. The FET 4100 includes a substrate 4110 having an n-type source 4112 and an n-type drain 4114. The FET 4100 also includes a source electrode 4120, a drain electrode 4122, and a gate electrode 4124, some or all of which are formed of ELR material, such as the modified and/or apertured ELR material described herein. The FET 4100 also includes an insulating layer 4126D, generally formed of an oxide, that insulates the gate electrode 4124 from the substrate 4110.

[00577] During operation, a positive voltage is applied to the gate electrode 4124, which generates an electric field within a channel region 4128 that enables electrons to flow in the channel region 4128 from the source 4112 to the drain 4114. That is, the generated electric field establishes a field effect that allows a current to flow within the device, switching the transistor to an "on" state.

[00578] MOSFETs are generally employed to amplify and/or switch electronic signals. They may be configured as NMOS or PMOS devices, or grouped together to form complementary metal oxide semiconductor (CMOS) circuits. Example devices that may employ ELR-based MOSFETs, such as in CMOS circuits, will now be discussed.

[00579] Figure 42-D is a schematic diagram 4200 illustrating an amplifier employing one or more ELR-based transistor elements. An amplifier 4210 includes one or more transistors 4220 formed at least in part of ELR components, such as bipolar junction transistors, field effect transistors, and so on. In operation, the amplifier 4210 receives an input signal 4230, amplifies the signal, and produces an amplified output signal 4240. Many types of devices may employ the amplifier 4210, including mobile devices,

televisions, radios, other devices that provide signal processing, radio transmission, sound reproduction, and so on.

[00580] In some examples, an amplifier employing ELR materials exhibits lower power dissipation and performs at higher speeds than an amplifier using conventional interconnects or metallization. The IC layout may be simplified because common resistance effects are reduced or eliminated, among other things.

[00581] Figure 43-D is a schematic diagram 4300 illustrating a switch employing one or more ELR-based transistor elements. A switch 4310 includes one or more ELR-based transistors 4315, such as ELR-based bipolar junction transistors, ELR-based field effect transistors, and so on. In operation as a logic gate, memory, and/or information storage device, the switch 4310 receives an input signal 4320, such as an input voltage, and produces an output signal 4322 as being either in an "on" state, which may be associated with a "1" in computing logic, or an "off" state, which may be associated with a "0" in computing logic.

[00582] In operation within a switched-mode power supply, the switch 4310 receives an input signal 4320, such as a current type, and produces an output signal that modifies the current type. For example, the switch 4310 may receive current from a grid and condition the current for use with certain devices.

[00583] As an example, in a switching regulator, a dc voltage (Vin) is converted to a pulse width modulated PWM waveform at a high frequency. The mark-space ratio of the PWM waveform generally sets the transfer ratio (Vout/Vin). The PWM waveform is then filtered by an inductor and capacitor to give the desired output voltage (Vout). There are three types of regulators: A step down regulator (Vin>Vout) is referred to as a *Buck* regulator, a step up regulator is referred to as a *Boost* regulator and an inverting regulator (Vout = −Vin) is referred to as a *Buck-Boost* regulator. All may benefit from elimination of resistance in transistors, interconnects, inductor windings, capacitor electrodes, and/or other ELR-based elements. The result is higher efficiency, among other things.

[00584] The switch 4310 may be utilized in other applications, such as in analog-to-digital converters, digital-to-analog converters, microprocessors and other logic-based elements, and so on. In some cases, utilization of ELR elements facilitates improved efficiency, faster clock speeds resulting in faster conversion times (ADC, DAC) and/or calculation/instruction times µC, µP, logic, simplified integrated circuit design, and other benefits.

[00585] Figure 44-D is a schematic diagram illustrating a microprocessor 4400 employing one or more ELR-based elements. The microprocessor 4400 includes a logic component 4410 that includes one or more ELR-based transistors 4415, an accumulator 4417, a program counter 4420, an address register 4425, a controller sequencer 4430, a decoder 4435, a data register 4440, random access memory (RAM) 4450, and/or input/output (I/O) components 4455. The microprocessor 4400 also includes various information paths 4460, some or all of which may be formed of the modified and/or apertured ELR materials described herein. The conductive paths 4460 may be control bus path 4462, data bus paths 4464, address bus paths 4466, and so on.

[00586] Forming the logic component 4410 and/or some or all of the information paths 4460 of the microprocessor 4400 with the ELR materials described herein enables the microprocessor 4400 to perform more quickly and efficiently, among other benefits.

[00587] In some examples, ELR material-semiconductor junctions enable devices, such as switches, amplifiers, logic devices, memory devices, and so on, to perform at very high speeds without requiring complex components and/or architectures, because there is virtually no propagation delay in circuits utilizing ELR interconnects, achieving a high fidelity signal over long distances due to minimal resistance distortion, among other benefits.

[00588] Of course, one of ordinary skill in the art will realize that other systems and devices may employ the ELR-based junctions and transistors described herein.

[00589] In some implementations, a transistor that includes modified ELR materials may be described as follows:

[00590] A junction device comprising: a modified extremely low resistance (ELR) element; and a semiconductor located proximate to the modified ELR element; wherein the modified ELR element includes a layer of ELR material and a modifying layer that modifies one or more operating characteristics of the layer of ELR material.

[00591] A method of forming a junction, the method comprising: forming a modified extremely low resistance (ELR) element on a substrate; and forming a semiconductor located proximate to the modified ELR element on the substrate.

[00592] A junction formed on a substrate, comprising: a first element composed of a semiconducting material; and a second element formed of an extremely low resistance (ELR) material that exhibits extremely low resistance to a flow of charge at temperatures between 150K and 313K.

[00593] A Josephson junction device comprising: a first modified extremely low resistance (ELR) element; a second modified extremely low resistance (ELR) element; and a semiconductor located between the first modified ELR element and the second modified ELR element; wherein the first modified ELR element or the second modified ELR element includes a layer of ELR material and a modifying layer that modifies one or more operating characteristics of the layer of ELR material.

[00594] A method of forming a Josephson junction, the method comprising: forming a first modified extremely low resistance (ELR) element on a substrate; forming a semiconductor proximate to the first modified ELR element on the substrate; and forming a second modified extremely low resistance (ELR) element proximate to the semiconductor on the substrate.

[00595] A Josephson junction formed on a substrate, comprising: a first element formed of an extremely low resistance material; a second element formed of a semiconducting material and positioned proximate to the first element; and a third element formed of an extremely low resistance material; wherein the first element or the third element are formed of extremely low resistance (ELR) material that exhibits extremely low resistance to a flow of charge at temperatures between 150K and 313K.

[00596] A transistor, comprising: a first nanowire formed of a modified extremely low resistance (ELR) material; a second nanowire formed of the modified extremely low resistance (ELR) material; and a semiconducting nanowire having a first end coupled to the first nanowire to form a first junction and a second end coupled to the second nanowire to form a second junction; wherein the modified ELR material includes a layer of ELR material and a modifying layer that modifies one or more operating characteristics of the layer of ELR material.

[00597] A device for controlling a current, the device comprising: a semiconducting nanowire; a first modified extremely low resistance (ELR) element that emits current into the semiconducting nanowire; a second modified extremely low resistance (ELR) element that collects current from the semiconducting nanowire; and a control element that applies a voltage to the semiconducting nanowire to control current within the semiconducting nanowire.

[00598] A transistor, comprising: a first junction formed of a first modified extremely low resistance (ELR) nanowire placed proximate to a first region of a semiconducting nanowire; and a second junction formed of a second modified extremely low resistance (ELR) nanowire placed proximate to a second region of the semiconducting nanowire.

[00599] A bipolar junction transistor, comprising: an emitter electrode formed of a modified extremely low resistance (ELR) material; a collector electrode formed of the modified extremely low resistance (ELR) material; a base electrode formed of the modified extremely low resistance (ELR) material; a semiconducting element having a first end coupled to the emitter electrode to form a first junction and a second end coupled to the collector electrode to form a second junction; wherein the modified ELR material includes a layer of ELR material and a modifying layer that modifies one or more operating characteristics of the layer of ELR material.

[00600] A device for controlling a current, the device comprising: a semiconducting element; a first modified extremely low resistance (ELR) element that emits current into the semiconducting element; a second modified extremely low resistance (ELR) element that collects current from the semiconducting element; and a control element that applies a voltage to the semiconducting element to control current within the semiconducting element.

[00601] A bipolar junction transistor, comprising: a first junction formed of a first modified extremely low resistance (ELR) element placed proximate to a first region of a semiconducting component; and a second junction formed of a second modified extremely low resistance (ELR) element placed proximate to a second region of the semiconducting component.

[00602] A metal oxide semiconducting field effect transistor (MOSFET), comprising: a source electrode formed of a modified extremely low resistance (ELR) material; a drain electrode formed of the modified extremely low resistance (ELR) material; and a gate electrode formed of the modified extremely low resistance (ELR) material; wherein the modified ELR material includes a layer of ELR material and a modifying layer that modifies one or more operating characteristics of the layer of ELR material.

[00603] A device for controlling a current, the device comprising: a semiconducting region; a first modified extremely low resistance (ELR) element that provides a source of electrons into the semiconducting element; a second modified extremely low resistance (ELR) element that receives electrons from the semiconducting element; and a control element that applies a voltage to the semiconducting element to control a flow of electrons within the semiconducting element.

[00604] An electrode configured to be utilized by a metal oxide semiconducting field effect transistor (MOSFET), the electrode comprising: a layer of extremely low resistance

(ELR) material; and a modifying layer that modifies one or more operating characteristics of the layer of ELR material.

[00605] A switch, comprising: a metal oxide semiconducting field effect transistor (MOSFET), comprising: a source electrode formed of a modified extremely low resistance (ELR) material; a drain electrode formed of the modified extremely low resistance (ELR) material; and a gate electrode formed of the modified extremely low resistance (ELR) material; wherein the modified ELR material includes a layer of ELR material and a modifying layer that modifies one or more operating characteristics of the layer of ELR material.

[00606] A logic device, comprising: a semiconducting region; a first modified extremely low resistance (ELR) element that provides a source of electrons into the semiconducting element; a second modified extremely low resistance (ELR) element that receives electrons from the semiconducting element; and a control element that applies a voltage to the semiconducting element to control a flow of electrons within the semiconducting element; wherein an actual flow of electrons indicates a first logic state corresponding to a 1, and a lack of flow of electrons indicates a second logic state corresponding to a 0.

[00607] A switch, comprising: an emitter configured to emit one or more electrons into a semiconducting element; and a collector configure to collect one or more electrons from the semiconducting element; wherein the emitter or collector includes a modified extremely low resistance (ELR) material.

[00608] An amplifier, comprising: a metal oxide semiconducting field effect transistor (MOSFET), comprising: a source electrode formed of a modified extremely low resistance (ELR) material; a drain electrode formed of the modified extremely low resistance (ELR) material; and a gate electrode formed of the modified extremely low resistance (ELR) material; wherein the modified ELR material includes a layer of ELR material and a modifying layer that modifies one or more operating characteristics of the layer of ELR material.

[00609] An amplifier, comprising: an emitter configured to emit one or more electrons into a semiconducting element; and a collector configured to collect one or more electrons from the semiconducting element; wherein the emitter or collector includes a modified extremely low resistance (ELR) material.

[00610] A method of amplifying a signal, the method comprising: receiving a current at an emitter; emitting electrons into a semiconducting element based on the received

current; applying a voltage to the emitted current that achieves a gain in voltage or current with respect to the received current; and collecting an amplified current in a collector electrode formed of a modified extremely low resistance (ELR) material.

[00611] An amplifier, comprising: a metal oxide semiconducting field effect transistor (MOSFET), comprising: a source electrode formed of a modified extremely low resistance (ELR) material; a drain electrode formed of the modified extremely low resistance (ELR) material; and a gate electrode formed of the modified extremely low resistance (ELR) material; and a cooling system configured to maintain a temperature of the MOSFET at a certain temperature lower than an ambient temperature surrounding the MOSFET; wherein the modified ELR material includes a layer of ELR material and a modifying layer that modifies one or more operating characteristics of the layer of ELR material.

[00612] A junction device comprising: a modified extremely low resistance (ELR) element; and a semiconductor located proximate to the modified ELR element; and a cooling component that maintains the modified ELR element at a temperature in which the modified ELR element propagates charge at extremely low resistance; wherein the modified ELR element includes a layer of ELR material and a modifying layer that modifies one or more operating characteristics of the layer of ELR material.

[00613] A device for controlling a current, the device comprising: a semiconducting region; a first modified extremely low resistance (ELR) element that provides a source of electrons into the semiconducting element; a second modified extremely low resistance (ELR) element that receives electrons from the semiconducting element; a control element that applies a voltage to the semiconducting element to control a flow of electrons within the semiconducting element; and a temperature component that maintains the first ELR element, the second ELR element, or the third ELR element at a temperature lower than an ambient temperature of the device.

[00614] An information storage device, comprising: a memory region; a first modified ELR element that provides a source of electric charge into the memory region; a second modified ELR element that receives electric charge from the memory region.

[00615] A memory device, comprising: a semiconducting region; a first modified extremely low resistance (ELR) element that provides a source of electrons into the semiconducting element; a second modified extremely low resistance (ELR) element that receives electrons from the semiconducting element; and a control element that applies a voltage to the semiconducting element to control a flow of electrons within the

semiconducting element; wherein an actual flow of electrons indicates a first logic state corresponding to a 1, and a lack of flow of electrons indicates a second logic state corresponding to a 0.

Chapter 8 – Integrated Circuits Formed of ELR Materials

Part A – Integrated Circuit Devices

[00616] This section of the description refers to Figures 1-36 and Figures 37-E through Figure 45-E; accordingly all reference numbers included in this section refer to elements found in such figures.

[00617] Integrated circuit components that are formed of modified extremely low resistance (ELR) materials are described. A modified ELR material can be, for example, a film, a tape, a foil, or a nanowire. However, for ease of description it is assumed for the examples herein that a modified ELR material is a film, although other implementations can be used. The modified ELR materials provide extremely low resistances to current at temperatures higher than temperatures normally associated with current high temperature superconductors (HTS), enhancing the operational characteristics of the integrated circuits at these higher temperatures, among other benefits.

[00618] In some examples, the modified ELR films are manufactured based on the type of materials used in the integrated circuit, the application of the modified ELR film, the size of the component employing the modified ELR film, the operational requirements of a device or machine employing the modified ELR film, and so on. As such, during the design and manufacturing of an integrated circuit, the material used as a base layer of a modified ELR film and/or the material used as a modifying layer of the modified ELR film may be selected based on various considerations and desired operating and/or manufacturing characteristics.

[00619] Figure 37-E is a schematic diagram illustrating a cut-away view of a conductive path 3700E formed, at least in part, of modified, apertured, and/or other new ELR materials, such as ELR materials having an ELR material base layer 3704 and a modifying layer 3706 formed on the base layer 3704. While various examples of the invention are described with reference to "modified ELR materials" and/or various configurations of modified ELR materials (e.g., modified ELR films, etc.), it will be appreciated that any of the improved ELR materials described herein may be used, including, for example, modified ELR materials (e.g., modified ELR material 1060, etc.), apertured ELR materials, and/or other new ELR materials in accordance with various aspects of the invention. As described herein, among other aspects, these improved

ELR materials have at least one improved operating characteristic which in some examples, includes operating in an ELR state at temperatures greater than 150K.

[00620] Various suitable modified ELR films are described in detail herein. Such a conductive path, when implemented in an integrated circuit, can be used, for example, for distributing power and propagating signals between circuit components in microprocessors, microcomputers, microcontrollers, digital signal processors (DSPs), systems-on-chip (SoCs), disk drive controllers, memories, application specific integrated circuits (ASICs), application specific standard products (ASSPs), field programmable gate arrays (FPGAs), or practically any other semiconductor integrated circuit.

[00621] As shown in the example of Figure 37-E, the conductive path includes an ELR material base layer 3704 and a modifying layer 3706 formed on the base layer 3704. The conductive path can be formed on a substrate 3702, for example, the silicon substrate of an integrated circuit. The conductive path can also be formed on top of other IC layers. Being formed of a modified ELR film, the conductive path 3700 provides little or no resistance to the flow of current in the conductive path at temperatures higher than those used in conventional HTS materials, such as room or ambient temperatures (~21C).

[00622] The material or dimensions of the substrate 3702 may be selected based on a variety of factors. For example, selecting a substrate material having a higher dielectric constant will generally reduce capacitance seen by a transmission line, and thus decrease the power necessary to drive a signal. One skilled in the art will appreciate the substrate may be formed of a number of different materials and into a number of different shapes in order to achieve certain desired properties and/or operating characteristics.

[00623] In some examples, the modified ELR conductive path provides extremely low resistance to the flow of current at temperatures between the transition temperatures of conventional HTS materials (e.g., can be in a range of ~80 to ~135K) and room temperatures (~294K). In these examples, the conductive path may include a cooling system (not shown), such as a cryocooler or cryostat, used to cool the conductive path 3700 to a critical temperature for the type of modified ELR film utilized for the conductive path 3700. For example, the cooling system may be a system capable of cooling the conductive path to a temperature similar to that of liquid Freon, to a temperature similar to that of frozen water, or other temperatures discussed herein. That is, the cooling system may be selected based on the type and structure of the modified ELR film utilized for the conductive path 3700.

[00624] Figure 38-E is a schematic diagram, which represents an example model of a conductive path formed from a modified ELR film. The model includes an input, I, and an output, O. R_I and R_O correspond to the respective resistances of the connecting materials on the input and output end of conducting path formed from the modified ELR film. R_{V1}, R_{V2}, R_{V3}, and R_{V4} correspond to resistances of vias and/or other connections from the internal conductive path to the outer skin of the conducting path. R_{W1} and R_{W2} correspond to the resistances of the internal conductive path of the modified ELR film. R_{S1}–R_{S4}, and C_{S1}–C_{S5} correspond to the transmission line model of the outer skin of the conducting path. The elements encompassed by the dashed line 3802 can be serially duplicated at position P for each via (or other connection) on the conducting path. The example model of Figure 38-E shows a branch B_1 which connects to a via (represented by R_{V4}) and the output O_I destination series path. In some examples, the model can include more elements including inductors.

[00625] Due to the extremely low resistance (represented by R_{W1} and R_{W2} of the model) of a conductive path formed from a modified ELR film, a signal propagating on the conductive path has a wave-front-delay time constant approaching zero. A signal propagates through the crystalline structure of a modified ELR film in a manner analogous to that of a waveguide, unencumbered by the capacitance of the outside environment. However, the signal also propagates on the outside skin of the modified ELR film which experiences normal resistance (represented by R_{S1}–R_{S4} of the model) and the capacitance (represented by C_{S1}–C_{S5} of the model) of the surrounding environment. Thus, the signal propagating through the crystalline structure of the modified ELR film can reach the destination node and change the voltage of the node before the outside skin has completely achieved its changed voltage.

[00626] As discussed herein, many integrated circuit devices and systems may utilize, employ and/or incorporate modified ELR conductive paths that exhibit extremely low resistances at high or ambient temperatures. In general, a device or system that provides a path for a current of electrons may incorporate the modified ELR conductive paths as described herein. The following section describes a few example devices, systems, and/or applications. One of ordinary skill will appreciate that other devices, systems, and/or applications may also utilize the modified ELR conductive paths.

[00627] In some examples, electrostatic discharge (ESD) protection routing of an integrated circuit can utilize the modified ELR conductive paths as described herein. Figure 39-E is a diagram of an example integrated circuit including ESD protection

routing formed of modified ELR conductive paths. As shown in Figure 39-E, modified ELR material is used to implement the conductive path 3902, which establishes a connection between the normal signal path 3904 (which connects to input/output pad 3914 of the integrated circuit), and an ESD protection circuit 3906. Modified ELR material may also be used with conductive path 3908, which connects between the ESD protection circuit 3906 and ground 3910. Since, in some examples, a modified ELR conductive path can be directional, i.e., current flows along a particular plane of the modified ELR material, the ESD protection network of Figure 39-E may utilize two substantially orthogonal layers coupled together by vias, such as via 3912, to route the ESD to ground. In other examples, the normal signal path 3904 can also be formed of modified ELR material.

[00628] Modern integrated circuit technologies, with smaller feature size, have become much more vulnerable to ESD and manufacturers have had to develop technologies to handle ESD protection. Two problems are present in conventional technology for mitigating ESD events. The first is quickly detecting the ESD event and the second is conducting the charge through various routed circuits in a limited time before the charge can build up voltage reaching a damaging threshold. Appropriate protection ratings are difficult to achieve using conventional materials because the smaller transistors of modern integrated circuits have a lower breakdown voltage.

[00629] Implementing the ESD protection network of modified ELR material allows for sufficient protection ratings for ESD protection. First, because the conductive path 3902 between the normal signal path and the ESD protection circuit is implemented using modified ELR material, the ESD signal has a wave-front-delay time constant approaching zero. This allows the ESD protection circuit 3906 to detect the ESD event nearly instantaneously. A modified ELR material ESD protection network may provide an extremely quick response to sensing the ESD event and triggering the protection, in addition to providing current conduction for the ESD event, directing the ESD into appropriately designed paths (e.g., conductive path 3908) before the charge can cause the voltage to build up to a level which damages circuit structures. The ESD protection voltage rating is directly proportional to how fast the ESD protection circuitry reacts to an ESD event. For example, an ESD protection circuit using conventional materials typically has a rating of 2,000 V Human-Body Model (HBM), while an ESD protection circuit using conductive paths formed of modified ELR materials might easily achieve a 16,000 V HBM rating because the response is sped up by eight fold or greater.

[00630] An ESD protection network from modified ELR conductive paths can be implemented on, for example: microprocessors, microcomputers, microcontrollers, DSPs, SoCs, disk drive controllers, memories, ASICs, ASSPs, FPGAs, neural networks, sensor arrays, MEMS, and generally any other semiconductor integrated circuit.

[00631] In some examples, the resistance of modified ELR conductive paths can be altered to create resistors in defined locations. The resistors can be used as components in circuits of the integrated circuit. For example, the resistors can be used in analog integrated circuits such as filters and amplifiers. The timing of digital circuits can be modified by adding resistance to a clock network. Signal integrity in critical areas can be improved by inserting extra resistance in the conductive path that carries the signal.

[00632] Figure 40-E is a diagram of an example laser programmable element on a conductive path formed from modified ELR material. The modified ELR conductive path 4002 of Figure 40-E includes a laser-modified section 4006. Integrated circuit chips typically have a passivation layer on the surface of the chip. In some examples this passivation layer is removed to create an opening 4004 to expose the modified ELR conductive path to the laser. When the laser modified section 4006 is exposed to a laser the resistance of the section is increased relative to the surrounding conductive path. In some examples, the energy from the laser rearranges the molecular structure of the conductive path at the laser-modified section such that the crystalline structure of the modified ELR material no longer acts as a waveguide. In other examples, the modifying layer of the modified ELR material is ablated by the laser and the reduced resistance that the modifying layer facilitates is lost. In other examples, both the modifying layer of the modified ELR material is ablated and the molecular structure of the conductive path is altered by the laser.

[00633] The dimensions of the laser-modified section define the resistance the section provides in the modified ELR conductive path. A laser modified section of a modified ELR conductive path can provide a resistor "insertion" into circuits, after the circuit has been manufactured, and can be particularly valuable for analog circuits as well as "tweaking" oscillators for changing clock frequencies on chips. In some examples, a linearly continuous length of modified ELR conductive path can be altered to provide the desired resistance. In other examples, multiple discrete sections of the modified ELR conductive path can be laser modified to provide an overall series resistance.

[00634] For example, Figure 41-E is a diagram of an example multi-bit laser programmable element on a conductive path formed from modified ELR material. Figure

41-E depicts modified ELR conductive paths 4102-4108 having various resistances which are made up of a number of discrete laser modified sections. As described above, in some examples, an opening 4410 in the passivation layer is provided to expose the conductive paths to the laser. Conductive path 4102 includes a single element resistance 4112 as discussed above with reference to Figure 40-E. Conductive path 4104 includes two discrete laser modified sections 4114 and 4116 which add together to provide a total resistance for the conductive path 4104. It should be apparent to one of skill in the art that various configurations and dimensions of laser-modified sections can be combined to provide a desired resistance for the conductive path. As will be appreciated, other programming mechanisms such as ion-beams and electron-beams may be suitable for programming modified ELR conductive paths in certain applications.

[00635] In some examples, the resistance of modified ELR conductive paths can be temporarily altered by the presence of a magnetic field. The ELR state of the modified ELR material cannot exist in the presence of a magnetic field greater than a critical value, even at temperatures as low as absolute zero. This critical magnetic field is strongly correlated with the critical temperature for the modified ELR material. In some examples, modified ELR materials show two critical magnetic field values, one at the onset of a mixed ELR and normal state and one where ELR ceases. The property of mixed ELR state can be used to implement resistances of varying value by varying the magnetic field.

[00636] Figure 42-E is a schematic diagram illustrating a cut-away view of an example integrated circuit having a magnetically programmable element on a conductive path formed from modified ELR material. The integrated circuit includes a semiconductor substrate 4201; dielectric material 4202; interconnect layers 4203, 4205, 4207, 4210, 4212, 4214, 4216, and 4218; via layers 4204, 4206, 4208, 4211, 4213, 4215, and 4217; and a void 4219 which defines a magnetically programmable element 4220. In some examples, at least interconnect layer 4212 is formed from modified ELR material.

[00637] When the example integrated circuit of Figure 42-E is exposed to a magnetic field that is stronger than the critical magnetic field, the resistance of interconnect layer 4212 increases. The interconnect layers 4209 above the interconnect layer 4212 act as a shield to the magnetic field such that the void 4219 in the shielding layers 4209 defines a magnetically programmable element 4220. In some examples, multiple voids can define multiple magnetically programmable elements. In one example, each of the multiple

magnetically programmable elements can be exposed to magnetic fields of a different strength to create various different resistances.

[00638] A magnetically programmable element in an integrated circuit can have many uses. For example, the elements can be used in analog integrated circuits as resistors that can be dynamically added, removed, and/or adjusted. The timing of digital circuits can be adjusted by adding, removing, and/or adjusting resistance by exposing a magnetically programmable element to a magnetic field. Signal integrity in critical areas can be improved by inserting extra resistance by exposing the conductive path that carries the signal to a magnetic field. A magnetically programmable element or a matrix of magnetically programmable elements can be used to measure a magnetic field similar to the way a thermistor is used to measure temperature.

[00639] The magnetic field can be provided by a device installed near the magnetically programmable element. For example, the device may be a permanent magnet or an electromagnet. Figure 43-E is a diagram of an example magnetically programmable element activated by a magnetoresistive random access memory (MRAM) cell. In the example of Figure 43-E, a conductive path 4302 of modified ELR material is formed near an MRAM cell 4304. While the source of the magnetic field 4308 in the example of Figure 43-E and Figure 44-E below are described as being MRAM cells, any magnetic field source such as an ELR sensor/antenna described in Appendix A can be used to produce the magnetic field.

[00640] The MRAM cell has at least two states and the magnetic field produced by the MRAM cell can vary depending on the state. The MRAM cell is in close enough proximity to the conductive path 4302 that the magnetic field produced by the MRAM cell is above the critical magnetic field for the conductive path for at least one state of the MRAM cell. In some examples, the width of the conductive path near the MRAM cell is reduced, for example, the reduced width section 4306. This reduction in width can affect the critical magnetic field required to change the resistance of the reduced width section.

[00641] In some examples, more than one MRAM cell can be distributed or localized along a conductive path to implement multiple resistors of varying resistance. Figure 44-E is an example diagram of multiple MRAM cells distributed along a modified ELR conductive path. As shown in Figure 44-E, each conductive path 4402-4408 has multiple MRAM cells, which can produce a magnetic field for a segment of the conductive path. Each MRAM cell can be selectively activated thereby making the resistance of the conductive path variable. For example, MRAM cell 4410 is in a first state, which is

producing a magnetic field above the critical magnetic field for a segment 4412 of modified ELR conductive path 4402. The MRAM cell 4411 is in a second state, which does not produce a magnetic field above the critical magnetic field for a segment 4413 of the modified ELR conductive path 4402.

[00642] Multiple segments of a modified ELR conductive path can be exposed to magnetic fields creating multiple resistance values. For example MRAM cells 4414 and 4416 can both be in the first state and produce the critical magnetic field for segments 4418 and 4420 on the modified ELR conductive path 4404. Any number of segments of varying length can be combined to create almost limitless possible resistances produced on a conductive path. This arrangement of multiple MRAM cells, or other magnetic field sources, can be used, for example, in filters to create an adaptive filter where the resistance of the filter can be modified. The arrangement can also be used to adjust the impedance of a transmission line for matching purposes.

[00643] In some examples, a segment of a modified ELR conductive path can be used as a current limiting device by modifying the dimensions of the segment such that the current flowing through the conductive path rises above the critical current at the modified segment. For example, Figure 45-E is a diagram of a modified ELR conductive path 4502 with a current limiting segment 4504. While the example of Figure 45-E includes a reduced width segment of modified ELR material, one of skill in the art will appreciate that other dimensions of the modified ELR material can be changed. For example, the segment of modified ELR material can be made thinner or a multi-layer modified ELR material can have fewer layers.

[00644] In some examples, multiple elements can be created on a modified ELR conductive path. By designing the specific width and thickness as needed for each particular element, specific critical current could be reached in each specific case. Each particular element operates with negligible resistance in a normal use case when the current is below the critical current, but to meet some design strategies (e.g., mitigating a fault or for other desired conditions) when the current exceeds a segment's particular critical current the segment becomes more resistive than the rest of the conductive path. As described above, the resistance of the segment can be defined by thickness, width, and/or length of the segment.

[00645] In some examples, transistors or microelectromechanical systems (MEMS) switches can be employed to trigger when the critical current is reached in a particular segment of the conductive path. For example, a MEMS switch can be set to route current

through a current limiting segment in response to certain conditions but to otherwise route the current through an alternative path.

[00646] In some examples, some or all of the systems and devices described herein may employ low cost cooling systems in applications where the specific modified ELR materials utilized by the application exhibit extremely low resistances at temperatures lower than ambient temperatures. As discussed herein, in these examples the application may include a cooling system (not shown), such as a system that cools a modified ELR conductive path to a temperature similar to that of the boiling point of liquid Freon, to a temperature similar to that of a melting point of water, or other temperatures discussed herein. The cooling system may be selected based on the type and structure of the ELR materials utilized by the application.

[00647] In addition to the systems, devices, and/or applications described herein, one skilled in the art will realize that other integrated circuit systems, devices, and applications may utilize the ELR conductive paths described herein.

Part B – Integrated Circuits and MEMS Devices

[00648] This section of the description refers to Figures 1-36 and Figures 37-F through Figure 45-F; accordingly all reference numbers included in this section refer to elements found in such figures.

[00649] Various implementations of the invention generally relate to extremely low resistance interconnects (ELRI), such as interconnects incorporating modified, apertured, and/or other new ELR materials. In some implementations, the ELRI can have a first layer comprised of an extremely low resistance (ELR) material and a second layer comprised of a modifying material bonded to the ELR material of the first layer. The ELRI can be used in a variety of systems and methods to create various improvements. Some examples where various efficiencies are created include, but are not limited to, systems and methods using ELRI for connecting microelectromechanical systems (MEMS) to an analog circuit on a semiconductor integrated circuit (IC), systems and methods using ELRI for connecting multiple MEMS together on an IC or on an IC mounting substrate, systems and methods for using ELRI for passive components used with MEMS on a semiconductor IC or on a mounting substrate, and systems and methods using ELRI for connecting MEMS to other circuits on an IC mounting substrate or system-in-package (SiP).

[00650] Some implementations provide for systems and methods using ELRI to connect MEMS to analog circuits on a semiconductor IC. Various implementations use ELRI

material to implement the conductive paths for signals to propagate between analog circuit functions and MEMS elements. These conductive paths can have negligible resistance and have a wave-front-delay time constant approaching zero. As such, the delay of signals and drive current in the electrical interactions can be significantly reduced.

[00651] In accordance with various implementations, ELRI material can also be used to connect multiple MEMS together on an IC, on an IC mounting substrate, or elsewhere within an IC package. For example, an ELRI material can be used to implement the conductive paths for signals to propagate between various MEMS circuits on an IC. These conductive paths connecting various MEMS can combine or compensate different MEMS parameters or attributes creating a MEMS network or a virtual Multi-MEMS in the sense that they act electrically as one MEMS while having multiple and possibly variable parameters or attributes.

[00652] In one or more implementations, ELRI can be used in passive components on a MEMS on a semiconductor IC or on a mounting substrate. For example, in some implementations, an ELRI material can be used to implement passive components and/or the conductive paths between the passive components and other circuits. The conductive paths allow for signals to propagate with negligible resistance and with a wave-front-delay time constant approaching zero. The use of the ELRI material significantly reduces the delay of signals and the drive current in their electrical interactions. Moreover, these ELRI passive components and connections can sometimes include MEMS elements, including ELRI as part of the MEMS structure.

[00653] In addition, various implementations of the invention provide for systems and methods using ELRI for connecting MEMS to other circuits on an IC mounting substrate or system-in-package (SiP). In some of these implementations, an ELRI material can be used to implement the conductive paths for signals to propagate between MEMS elements and circuit function components which can have a variety of beneficial effects. For example, the conductive paths can have a negligible resistance and a wave-front-delay time constant approaching zero, thereby significantly reducing delay of signals and drive current in their electrical interactions.

[00654] The ELRI can be manufactured based on the type of materials, the application of the ELRI, the size of the component employing the ELRI, the operational requirements of a device or machine employing the ELRI, and so on. As such, during the design and manufacturing, the material used as a base layer of an ELRI and/or the material used as

a modifying layer of the ELRI may be selected based on various considerations and desired operating and/or manufacturing characteristics. While various suitable geometries and configurations are shown and described herein for the layout and/or disposition of the modified ELR, numerous other geometries are possible. These other geometries include different patterns, configurations or layouts with respect to length and/or width in addition to differences in thickness of materials, use of different layers, ELR films having multiple adjacent modifying layers, multiple ELR films modified by a single modifying layer, and other three – dimensional structures. Thus any suitable modified ELR can be used depending upon the desired application and/or properties.

[00655] In the Figures, sizes of various depicted elements or components and the lateral sizes and thicknesses of various layers are not necessarily drawn to scale and these various elements may be arbitrarily enlarged or reduced to improve legibility. Also, component details have been abstracted in the Figures to exclude details such as precise geometric shape or positioning of components and certain precise connections between such components when such details are unnecessary to the detailed description of the invention. When such details are unnecessary to understanding the invention, the representative geometries, interconnections, and configurations shown are intended to be illustrative of general design or operating principles, not exhaustive.

[00656] Figure 37-F is a schematic illustrating a possible circuit design connecting MEMS 3710a – 3710d with analog circuits 3720a – 3720d using traditional interconnects such as 3730. In many circuit designs, analog circuits 3720a – 3720d interface with and measure various MEMS parameters. However, any measurement is degraded by the connection parasitic resistance limiting the signal accuracy. As shown in Figure 37-F, multiple analog circuits 3720a – 3720d are required to amplify the signals generated by the MEMS mechanical-to-electrical energy conversion, and also to compensate for the parasitic losses encountered by the signals propagating through the resistive conductors 3760 providing signal(s) to component 3740 in traditional technology. Typically, better functionality is provided when the analog circuits are placed in very close proximity to the MEMS. In some cases, however, the MEMS 3710a – 3710d cannot be located close to the analog circuits 3720a – 3720d for other design and manufacturing reasons. As a result, degraded performance from the connection parasitics resulting from the traditional conductive paths occur and additional design considerations are required for adequate performance. Similarly, when MEMS are connected to other circuits and/or

other components a similar degradation can occur when traditional conductive interconnects are used.

[00657] Some implementations of the invention provide for systems and methods using ELRI to connect MEMS to analog circuits on an IC. For example, the ELRI can be used to implement the conductive paths for signals to propagate between analog circuit functions and MEMS elements. These conductive paths can have negligible resistance and can have a wave-front-delay time constant approaching zero. As such, the delay of signals and drive current in the electrical interactions can be significantly reduced. In addition, the performance and accuracy tends to be superior over the use of traditional conductive paths by the reduced parasitic resistance of the connections to the MEMS circuits. Accordingly, the use of ELRI to connect the MEMS to components (e.g., analog circuits and/or other circuits) can allow the components to be connected to the MEMS circuits virtually independent of their location.

[00658] Figure 38-F is a schematic illustrating the use of ELRIs to connect MEMS to one or more analog circuits on an IC. In accordance with various implementations, the ELRI such as 3830, for connecting MEMS circuits 3810a – 3810d each to an analog circuit 3820 of an analog circuit block 3840, could be implemented on virtually any semiconductor IC with MEMS structures and analog circuits. The analog circuits can interface with and measure the MEMS parameters. However, with traditional interconnects any measurement degrades with the connection parasitics and limits the accuracy. As will be appreciated, using ELRI 3830 can allow the analog circuit 3820 to be connected to the MEMS circuits 3810a – 3810d virtually independent of their location and without substantial or significant parasitic resistance, and further may reduce the complexity of the required circuit design. The output of each analog circuit 3820 could be coupled through another ELRI 3860 to drive line 3850.

[00659] In some implementations of the invention, an IC is provided that includes one or more conductive paths, a MEMS, and a set of circuitry (e.g., analog circuit) connected to the MEMS through the one or more conductive paths. In some implementations, the one or more conductive paths are comprised of an ELRI having a first layer comprised of an ELR material (e.g., YBCO, BSCCO, or other) and a second layer comprised of a modifying material (e.g., chromium, copper, bismuth, cobalt, vanadium, titanium, rhodium, beryllium, gallium, selenium, silver or other) bonded to the ELR material of the first layer. In some implementations, the IC can have multiple levels of interconnect, each level separated from adjacent levels with an insulating dielectric having vias formed

to electrically couple adjacent interconnect levels as required to continue conductive paths. Layers and each of the multiple levels of interconnect can include at least one of the one or more conductive paths. In accordance with some implementations, the ELRI can be a superconductor or a perfect conductor at ambient temperatures, or under other suitably desirable conditions.

[00660] The MEMS can include one or more components. Examples include, but are not limited to, a radio frequency circuit, a tunable transmission line, a waveguide, a resonator, ELR components, passive components, ELR passive components, a quasi-optical component, a tunable inductor, a tunable capacitor, and/or an electromechanical filter. As other examples, the one or more components can include sensors to detect environmental parameters. Examples of the types of sensors than can be used include, but are not limited to, a pressure sensor, a temperature sensor, a light sensor, a vibration sensor, an accelerometer, a humidity sensor, an electric field sensor, and/or a sound sensor.

[00661] Some implementations provide for an electronic device (e.g., a wireless device, Wi-Fi device, a spread spectrum device, a wireless USB device, a Bluetooth® device, etc) that includes a power supply connected an IC. The IC can have one or more conductive paths comprised of an ELRI having a first layer comprised of an ELR material and a second layer comprised of a modifying material bonded to the ELR material of the first layer. In addition, a set of circuitry (e.g., an RF circuit, an analog circuit, a digital circuit, etc) can be connected to a MEMS device through the one or more conductive paths. In some implementations, the IC in the electronic device can also include an RF antenna, an RF amplifier, an RF filter, and/or an RF controller. In some cases, these components can be ELR components made from ELR material. For example, the RF antenna can have a first ELR antenna layer comprised of ELR material and a second ELR antenna layer comprised of modifying material bonded to the ELR material of the first ELR antenna layer.

[00662] Figure 39-F illustrates the use of ELRI 3910 for connecting a MEMS 3920 to other circuits or components 3930 on an IC Mounting Substrate or a SiP 3940. For example, the ELRI 3910 can be used to connect the MEMS 3920 to a microprocessor, a microcomputer, a microcontroller, a DSP, a system on chip (SoC), an antenna, a second MEMS, an ASIC, an ASSP, an FPGA, and/or other circuit, component, or device 3930. The techniques used in these implementations can be used to connect MEMS 3920 to other circuits or components 3930. In addition, these techniques can be implemented on

virtually any semiconductor IC mounting substrate containing a MEMS 3920 of same or varying types. For example, for a SiP, ELRI 3910 can be used to connect MEMS devices on the substrate to configure connections to ICs and other passive components, such as antennas, with no appreciable resistance allowing these elements to perform as though they were directly connected at their respective nodes, regardless of their physical location on the substrate.

[00663] In at least one implementation, an IC is provided that includes a MEMS, a network or components, and an IC mounting substrate. The IC mounting substrate can have one or more conductive paths comprised of an ELRI having a first layer comprised of an ELR material and a second layer comprised of a modifying material bonded to the ELR material of the first layer. The network of components can be connected to the MEMS through the one or more conductive paths. In some implementations, the network of components includes one or more ELRI passive components that are programmable, a microprocessor, a microcomputer, a microcontroller, a DSP, a system on chip (SoC), an antenna, a second MEMS, an ASIC, an ASSP, and/or an FPGA. In one implementation, the set of ELRI passive components are programmable to set a specific frequency or a Q of a transmitter circuit or a receiver circuit.

[00664] In some implementations, the MEMS can include one or more internal paths and/or components comprised of a first layer comprised of the ELR material and a second layer comprised of a modifying material bonded to the ELR material of the first layer. The one or more components can be electrical components and/or mechanical components. For example, in at least one implementation, the one or more components can include a set of ELRI passive components, a tunable transmission line, a waveguide, a resonator, a quasi-optical component, a tunable inductor, a tunable capacitor, an electromechanical filter, a sensor, a switch, an actuator, a structure, and/or other component.

[00665] The MEMS can also include, in some implementations, an input port to receive an input signal from outside the MEMS and/or an output port to transmit an internally generated signal outside of the MEMS. The input port can be connected to a component configured to receive the input signal and generate a response. In some cases, the input port and/or the output port can be connected to the component via one or more conductive paths to allow for signal transfer. In some implementations, the one or more conductive paths include a first layer comprised of an extremely low resistance (ELR)

material and a second layer comprised of a modifying material bonded to the ELR material of the first layer.

[00666] Various implementations also provide for an electronic device having a power supply connected to an IC. In accordance with these implementations, the IC can include an IC mounting substrate having one or more conductive paths comprised of an ELRI having a first layer comprised of an ELR material and a second layer comprised of a modifying material bonded to the ELR material of the first layer. In addition, the IC can have a MEMS and a network of other components (e.g., a microprocessor, a microcomputer, a microcontroller, a DSP, SoC, an antenna, an RF controller, an RF circuit, an RF amplifier, a second MEMS, an ASIC, an ASSP, an FPGA, a neural network, and/or other component) connected to the MEMS through the one or more conductive paths. In some implementations, the MEMS can include one or more of the following components: a tunable transmission line, a waveguide, a resonator, a quasi-optical component, a tunable inductor, a tunable capacitor, and/or an electromechanical filter.

[00667] Many advantages can result from using ELRI for connecting MEMS circuits to an analog circuit and/or other circuits/components on an IC or SiP. For example, since the one or more conductive paths can have a near-zero parasitic resistance, this would allow the MEMS to be connected to the set of circuitry or components independent of location on a package. In addition, ELRI would enable MEMS and the circuits or components to be integrated on an IC with optimized locations and minimized degradations due to parasitic resistance. As another example, ELRI would allow the MEMS and the analog circuits to be designed somewhat independently. This independent design could facilitate prompt development. Moreover, this would allow MEMS IP and analog circuits IP to be more freely utilized. With ELRI allowing more independence between MEMS and analog circuit designs, more quantity and variety could be integrated on an IC, so MEMS ICs would proliferate in new products – that proliferation providing the learning curve for improved product design and manufacturing.

[00668] Using this ELRI technology in an IC product synergistically favors utilizing other ELRI technologies. Examples include MEMS ELRI technologies such as ELRI for connecting multiple MEMS circuits, ELRI for connecting a MEMS to other circuits on a mounting substrate or a SiP, ELRI for 3D interconnects on an IC (which connects the IC to the mounting substrate on package), ELRI for power supply distribution on a mounting

substrate, and others, all of which further improves the development of all ELRI technologies and can improve the performance of the product.

[00669] The resistance of metal interconnects created by traditional techniques for connecting MEMS circuits can limit and/or degrade their parameters or attributes. As illustrated in Figure 40-F, some traditional designs have used amplifiers 4010a – 4010f on the output of each MEMS 4020a – 4020f to increase the signal strength. The output from amplifiers 4010a – 4010f are then interfaced (e.g., by an analog interface 4030) to combine and/or operate on the outputs of the MEMS circuits. However, with the use of ELRI in accordance with various implementations of the invention, the MEMS and interface can be connected in such a way as to negate the parasitic effect of the interconnection.

[00670] Figure 41-F is a schematic showing multiple MEMS 4110a – 4110f connected to an interface device 4120. In accordance with various implementations, ELRI material can be used to connect multiple MEMS 4110a – 4110f together on an IC, SiP, or on an IC mounting substrate 4130. For example, an ELRI material can be used to implement the conductive paths 4140 for signals to propagate between various MEMS circuits 4110a – 4110f on an IC. These conductive paths connecting various MEMS 4110a – 4110f can combine or compensate different MEMS parameters or attributes creating a MEMS network or a virtual multi-MEMS in the sense that they act electrically as one MEMS while having multiple and possibly variable parameters or attributes. In accordance with various implementations of the invention, ELRI for connecting MEMS circuits to other MEMS could be implemented on virtually any semiconductor IC with MEMS of same or varying types. In some cases, the ELRI will not degrade the output of the MEMS.

[00671] One example of virtual multi-MEMS is a MEMS capacitor connected through a MEMS switch to another MEMS capacitor as a "trim", to adjust margin. The "trim" component might or might not be subjugated to the same environmental forces that the primary encounters. Another is multiple MEMS sensing various environmental parameters. Examples include, but are not limited to, fluid pressure in a container, atmospheric pressure, temperature of the container, temperature of the air, ambient light, and vibration. The sensed environmental parameters can then be connected in an integrated control.

[00672] In some implementations, an IC is provided that includes a network of one or more MEMS, a set of circuitry, and one or more conductive paths. The one or more

conductive paths can include an ELRI having a first layer comprised of an ELR material and a second layer comprised of a modifying material bonded to the ELR material of the first layer. In some implementations, the IC can have multiple layers that each has at least one conductive path. The network of MEMS can be interconnected through the one or more conductive paths. In addition, the set of circuitry (e.g., a digital circuit and/or an analog circuit) can be coupled (directly or indirectly) to the network of MEMS through the one or more conductive paths. In some implementations, the one or more conductive paths can have a near-zero parasitic resistance allowing the first MEMS to be connected to the set of circuitry independent of design requirements previously imposed by conductive characteristics of prior art interconnect material.

[00673] In at least one implementation, the network of MEMS includes a first MEMS having an output port and a second MEMS having an input port connected to the output port of the first MEMS through the one or more conductive paths. In some cases, additional MEMS (e.g., a third MEMS, a fourth MEMS, etc) can also be implemented on a single IC. As illustrated in Figure 42-F, a multi-environment set of MEMS can be utilized. For example, MEMS 4210 can be configured to measure pressure, MEMS 4220 can be configured to measure temperature, MEMS 4230 can be configured to measure light, and MEMS 4240 can be configured to measure vibration. In some implementations, one of the MEMS, such as MEMS 4250, can include a radio frequency circuit, a sensor (e.g., a pressure sensor, a temperature sensor, a light sensor, a vibration sensor, an accelerometer, a humidity sensor, an electric field sensor, a magnetic field sensor, a sound sensor etc), an actuator (e.g., switch), and/or a mechanical or electrical structure (e.g., a tunable transmission line, a waveguide, a resonator, a quasi-optical component, a tunable inductor, a tunable capacitor, an electromechanical filter, etc).

[00674] In some implementations, an electronic device (e.g., wireless device) can be provided. The electronic device can include a power supply connected to an IC. The IC can have one or more conductive paths comprised of an ELRI having a first layer comprised of an ELR material and a second layer comprised of a modifying material bonded to the ELR material of the first layer. In various implementations, the IC also includes a network of one or more MEMS and a set of circuitry (e.g., an analog circuit) coupled to the network of MEMS through the one or more conductive paths. The IC and/or MEMS can include a variety of additional components some of which may be made from an ELR material. Examples include, but are not limited to, an RF circuit, an RF antenna, a tunable transmission line, a waveguide, a resonator, a quasi-optical

component, a tunable inductor, a tunable capacitor, an electromechanical filter, a sensor, actuator, and/or other electrical or mechanical structure.

[00675] Figure 43-F illustrates an IC assembly 4300 using ELRI 4310 for connecting multiple MEMS circuits 4320 to create virtual multi-MEMS. The network of MEMS 4320 created by these interconnections can be designed. For example, some of the MEMS 4320 can be switches and some can be sensors exposed to varying environmental constraints. With ELRI 4310 connecting one MEMS to another with negligible parasitics, the integrated multi-MEMS would act as one MEMS with multiple and varying parameters or attributes.

[00676] As illustrated in Figure 43-F, some implementations allow for MEMS 4320 to be implemented on an ASIC 4330 or other component. In the implementations shown in Figure 43-F, ASIC 4330 has regular pads 4340 and extended pads 4350. In addition, IC assembly 4300 and/or ASIC 4330 can use ELRI 3D interconnects 4360 to interconnect some of the components.

[00677] Being able to design a virtual multi-MEMS device on an IC offers greater capability, which opens vast opportunities to sense the environment and respond electronically. Using the ELRI in accordance with various implementations of the invention in an IC product also synergistically favors utilizing other ELRI technologies such as, but not limited to, ELRI for connecting MEMS circuits to an analog circuit on an IC, ELRI for "3D" interconnects, and/or ELRI for power supply distribution on a mounting substrate.

[00678] In one or more implementations, ELRI can be used in passive components in a MEMS on a semiconductor IC or on a mounting substrate. For example, in some implementations, an ELRI material can be used to implement passive components and/or the conductive paths between the passive components and other circuits/components. The conductive paths allow for signals to propagate with negligible resistance and with a wave-front-delay time constant approaching zero. As a result, the use of the ELRI material significantly reduces the delay of signals and the drive current in their electrical interactions. Moreover, these ELRI passive components and connections can sometimes include MEMS elements, including ELRI as part of the MEMS structure.

[00679] Various implementations create advantages over traditional systems and in some cases render certain MEMS manufacturing processes practical which would otherwise not produce components within usable limits. For example, the extremely low resistance enables integrating the passive components to "virtual nodes," as the

components don't exhibit the parasitic resistance of present art technology. As another example, ELRI passive components, especially when used with MEMS, can create near-ideal components otherwise not available for integrating with other conventional circuits on an IC or on a MEMS substrate (such as inductors or transformers). Also, capacitors and inductors can be connected to program the specific frequency and/or Q of transmitter and receiver circuits. Either analog or digital MEMS elements can be used. In one implementation, registers store bits to enable various capacitors of strategic values to program various capacitances as needed for achieving desired circuit attributes. In another implementation, capacitors of preset values are selectively connected to achieve desired circuit attributes.

[00680] In accordance with various implementations, ELRI routing can connect MEMS switches to passive components formed in ELRI material, with negligible parasitic resistance, creating near-ideal components for integrating with other conventional circuits on an IC or on a MEMS substrate. MEMS ELRI passive components can connect to trim the capacitance or inductance (such as to program the specific frequency and/or Q of transmitter and/or receiver circuits) with possibly the influence of environmental forces to which the MEMS is designed to respond. In some cases, ELRI passive component inductors could be formed as a transformer to perform as signal isolation.

[00681] Figure 44-F shows an IC 4400 having a MEMS 4410 (possibly having ELRI passive components), a set of passive components 4420 implemented on a mounting substrate of the IC or a component, and one or more conductive paths 4430. In accordance with the implementations shown, the one or more conductive paths 4430 include an ELR having a first layer comprised of an ELR material and a second layer comprised of a modifying material bonded to the ELR material of the first layer. The set of passive components 4420 can be connected to the MEMS 4410 through the one or more conductive paths 4430. In one or more implementations, an ELR antenna 4440 and a spiral ELR inductor 4450 can be implemented on the IC.

[00682] In some implementations, a second set of ELRI passive components can be implemented on the IC or on the MEMS. The set of ELRI passive components can be programmable. For example, the components can be programmed to set a specific frequency or Q of a transmitter circuit or a receiver circuit. As another example, a register can be used to store bits and using MEMS to select various capacitors to achieve the specific frequency. In some cases, the passive components can include a switch and/or a sensor made of ELRI material.

[00683] Some implementations use a cooling system to dynamically program one or more MEMS and/or ELRI components. For example, a resistive ELRI component can be used to program a MEMS. As the cooling system decreases the temperature, the resistance in the ELRI element decreases, effectively turning off the element. Similarly, as the temperature is raised to the critical temperature of the ELRI segment, the resistance in the ELRI element increases thereby changing a state of the MEMS or programmable component.

[00684] In at least one implementation, a conductive path can have an ELR material with multiple layers. Each layer can have a specific (and possibly different) thickness. The modifying layer can be attached to the top layer resulting in more stiffness for the top layer. As the temperature changes, so will the conductive properties of the different layers. For example, the top layer will have the lowest resistance and will act as a superconductor or perfect conductor at higher temperatures than the other layers since the top layer is bonded directly to the modifying layer. As the temperature drops, subsequent layers will become less resistive and act more like superconductors or perfect conductors in the order of closeness to the modifying layer. As will be appreciated, the changes in the temperature change the conductive properties in the different layers and as a result will change the Jc and Hc of the ELRI.

[00685] The MEMS, in various implementations, can include one or more internal paths comprised of a first MEMS layer comprised of the ELR material and a second MEMS layer comprised of a modifying material bonded to the ELR material of the first MEMS layer. The MEMS can also be configured to sense one or more environmental parameters by using a pressure sensor, a temperature sensor, a light sensor, a vibration sensor, an accelerometer, a humidity sensor, an electric field sensor, and/or a sound sensor.

[00686] Various implementations also provide for a device having a power supply and an IC. The IC can have one or more conductive paths comprised of an ELRI having a first layer comprised of an ELR material and a second layer comprised of a modifying material bonded to the ELR material of the first layer. In addition, the IC can have a MEMS connected to a set of passive components through the one or more conductive paths. In some cases, the MEMS can include an RF circuit coupled to the RF antenna 4450 on the IC. The MEMS may also include one or more of a tunable transmission line, a waveguide, a resonator, a quasi-optical component, a tunable inductor, a tunable capacitor, and an electromechanical filter and/or other components as discussed above.

[00687] ELRI for passive components can be used with MEMS to create near-ideal components otherwise not available for integrating, where a network of passive components could be designed, some being switches, some MEMS being sensors exposed to varying environmental constraints. With ELRI connecting them with negligible parasitics, the integrated near-ideal components would act as extensions of the MEMS with multiple and varying parameters or attributes. Being able to design a virtual near-ideal Multi-MEMS device on an IC offers an order of magnitude greater capability, which opens vast opportunities to sense the environment and respond electronically.

[00688] Again, using this ELRI technology in an IC product synergistically favors utilizing other ELRI technologies. Examples include, but are not limited to, ELRI for connecting MEMS circuits to an analog circuit on an IC, ELRI for "3D" interconnects on an IC (which connects the IC to the mounting substrate), and ELRI for power supply distribution on an IC, or ELRI for Power Supply distribution on a mounting substrate. These and other ELRI technologies, can further improve the performance of the IC product.

[00689] Figure 45-F is a flow chart 4500 showing a set of exemplary operations for manufacturing conductive paths, ELRI MEMS, and/or ELRI components on an IC. The ELRI can be manufactured based on the type of materials, the application of the ELRI, the size of the component employing the ELRI, the operational requirements of a device or machine employing the ELRI, and so on.

[00690] In the implementations shown in Figure 45-F, a first depositing operation 4510 deposits a first layer of extremely low resistance (ELR) material on an IC, substrate, or SiP. In accordance with various implementations, the first layer can comprise YBCO or BSCCO. A second layer comprised of a modifying material on the first layer of the ELR material creating ELR interconnects is deposited during a second depositing operation 4520. The second layer can include chromium, copper, bismuth, cobalt, vanadium, titanium, rhodium, beryllium, gallium, silver or selenium. The material used as the first or base layer of an ELRI and/or the material used as a modifying layer of the ELRI may be selected based on various considerations and desired operating and/or manufacturing characteristics. Examples include, cost, performance objectives, equipment available, materials available, and/or other considerations and characteristics. Processing operation 4530 processes the ELR interconnects to form various components, conductive paths, and/or interconnects. For example, in some implementations, an ELRI MEMS, ELRI passive components, an ELRI RF antenna, a power distribution system,

and/or a signal bus with one or more conductive paths capable of routing signals can be formed.

[00691] In addition to the systems, devices, and/or applications described herein, one skilled in the art will realize that other systems, devices, and application that include conductive paths may utilize the ELRIs described herein.

Part C – Integrated Circuit RF Devices

[00692] This section of the description refers to Figures 1-36 and Figures 37-G through Figure 41-G; accordingly all reference numbers included in this section refer to elements found in such figures.

[00693] Various implementations of the invention generally relate to extremely low resistance interconnects (ELRI), such as interconnects that include modified, apertured, and/or other ELR materials. In some implementations, the ELRI can have a first layer comprised of an extremely low resistance (ELR) material and a second layer comprised of a modifying material bonded to the ELR material of the first layer. The ELRI can be used in a variety of systems and methods to create various improvements. Some examples where various efficiencies are created include, but are not limited to, systems and methods using ELRI in radio frequency (RF) circuits on an IC, systems and methods using ELRI for RF antenna(e) on a semiconductor IC, systems and methods for using ELRI in passive elements of RF transmitter and receiver circuits on a monolithic microwave IC (MMIC), and systems and methods using ELRI in embedded RF circuit functions on a semiconductor IC.

[00694] Some implementations provide for RF circuits on an IC that can use an ELRI material to implement the conductive paths for the RF circuits on the IC. The use of the ELRI material can result in a higher Q capability. As such, an IC using ELRI in the conductive paths can, depending on the desired application, require less active circuits and/or less semiconductor area for the various circuits. In some implementations, ELRI can be used to connect multiple individual blocks of RF circuits and/or other technologies, including other ELRI technologies.

[00695] In accordance with various implementations, ELRI material can be used to implement the conductive paths for RF antenna topologies on an IC. The resulting antenna topology can have an area less than conventional substrate topologies that do not use ELRI material. In addition, the RF antenna can be located in isolated locations without incurring the penalty of interconnect resistance, not necessarily having an off-chip interface, thereby yielding higher Q capability. As such, the RF antenna

topologies resulting from the use of ELRI material in the conductive paths can use less active circuits and thus less semiconductor area for the various circuits.

[00696] In one or more implementations, ELRI can be used in passive elements of RF transmitter and receiver circuits on an MMIC. By using the ELRI material to implement passive elements and/or the conductive paths connecting RF circuits, the signals can propagate with a wave-front-delay time constant approaching zero. As a result, the delay of signals between the various functional elements can be virtually eliminated or significantly reduced. In some implementations, the ELRI material can form very high Q transmitter and receiver circuits.

[00697] In addition, various implementations of the invention provide for systems and methods using ELRI in embedded RF circuit functions on a semiconductor IC. In some of these implementations, the ELRI material can be used to implement the conductive paths for signals to propagate with a wave-front-delay time constant approaching zero. As a result, the delay of interface signals between the embedded RF circuit function(s) and the sub-systems enveloping the function(s), or between sub-system blocks connected to embedded function(s) can be significantly reduced or even eliminated. This makes these various blocks like virtual blocks, in the sense that each respective connecting signal seems to be touching its respective embedded node, so that it performs as the computer model indicates, with negligible parasitic variance, regardless of its actual physical location with respect to the embedded RF circuit function.

[00698] The ELRI can be manufactured based on the type of materials, the application of the ELRI, the size of the component employing the ELRI, the operational requirements of a device or machine employing the ELRI, and so on. As such, during the design and manufacturing, the material used as a base layer of an ELRI and/or the material used as a modifying layer of the ELRI may be selected based on various considerations and desired operating and/or manufacturing characteristics.

[00699] While various suitable geometries and configurations are shown and described herein for the layout and/or disposition of the modified ELR, numerous other geometries are possible. These other geometries include different patterns, configurations or layouts with respect to length and/or width in addition to differences in thickness of materials, use of different layers, ELR films having multiple adjacent modifying layers, multiple ELR films modified by a single modifying layer, and other three – dimensional structures. Thus any suitable modified ELR can be used depending upon the desired application and/or properties.

[00700] In accordance with various implementations of the invention, ELR RF circuits and/or antennas can be implemented on an IC. The RF circuits and/or antennas can use ELRI material, such as modified, apertured, and/or other new ELR material, to implement the conductive paths that connect the RF circuitry to the antennas and the conductive paths that are within the RF circuitry and/or the antennas. The use of the ELRI material can have many advantages over traditional interconnect material that can be appreciated by one of ordinary skill in the art.

[00701] While various examples of the invention are described with reference to "modified ELR materials" and/or various configurations of modified ELR materials (e.g., modified ELR films, etc.), it will be appreciated that any of the improved ELR materials described herein may be used, including, for example, modified ELR materials (e.g., modified ELR material 1060, etc.), apertured ELR materials, and/or other new ELR materials in accordance with various aspects of the invention. As described herein, among other aspects, these improved ELR materials have at least one improved operating characteristic, which in some examples includes operating in an ELR state at temperatures greater than 150K.

[00702] For example, by using ELRI the RF antenna can be located in isolated locations without incurring the penalty of interconnect resistance, not necessarily having an off-chip interface, thereby yielding higher Q capability. As such, the RF antenna topologies resulting from the use of ELRI material in the conductive paths can require less active circuits and thus less semiconductor area for the various circuits. In some implementations, ELRI can be used to connect multiple individual blocks of RF circuits and/or other technologies, including other ELRI technologies. Moreover, because ELRI produces extremely low losses, RF antenna architectures and circuitry can be devised and implemented that would otherwise be impractical on an IC, and can even significantly reduce the active circuit amplification and filtering.

[00703] As another example, the use of ELRI also enables the IC design to dispose an RF antenna more closely to RF circuitry on the IC with improved conductive interconnects. This tends to result in lower parasitic losses yielding higher Q, such that design requirements can be simplified, e.g., avoiding special semiconductor processes and off package design. In addition, new RF products could be developed that were not feasible with prior art technology, such as single chip RF transceivers with much higher

Q. This could, e.g., allow handheld instruments to address a large number of separate channels.

[00704] Figure 37-G illustrates the use of ELRI materials implementing the conductive paths for RF circuits on an IC 3710. In traditional integrated circuits, the RF circuitry is implemented off the chip from controller functions because of isolation requirements imposing special, more costly semiconductor processes. These processes, however, are often not cost effective for implementing the digital circuitry such as controller functions. In contrast, with ELRI connecting the RF antennas 3720 directly to the RF circuits, less parasitic losses are encountered, so RF circuitry can be implemented on the IC 3710 of the same chip with the digital circuitry without the need for special isolation or other more costly semiconductor processes.

[00705] In accordance with various implementations of the invention, when an ELRI material is used to implement the conductive paths 3730 and/or 3760 for RF circuits on IC 3710, a higher Q capability can result when compared to traditional circuits that do not use ELRI materials. In some implementations, ELRI can be used to connect individual blocks of the RF circuits as well as other technologies, including other ELRI technologies. As such, the RF circuits resulting from the use of ELRI material in the conductive paths can use less active circuits and possibly less semiconductor area for various circuits. In some implementations, RF circuits can be implemented on microprocessors, microcomputers, microcontrollers, digital signal processors (DSPs), systems on chips (SoC), disk drive controllers, ASICs, ASSPs, FPGAs, and/or any other semiconductor IC in various systems such as Bluetooth®, wireless USB, Wi-Fi, or other RF transceiver interfaces. According to certain aspects, using ELR as power and ground planes would reduce the noise coupling from digital to analog circuits.

[00706] As illustrated in Fig. 37-G, some implementations of the invention provide for an IC 3710 comprising an IC mounting substrate, an RF antenna 3720, and an RF circuit. The IC mounting substrate can have multiple layers and one or more conductive paths 3730 for signal routing. The one or more conductive paths 3730 can be made of a modified extremely low resistance interconnect (ELRI) having a first layer comprised of an extremely low resistance (ELR) material. In addition, the one or more conductive paths 3730 can also have a second layer comprised of a modifying material bonded to the ELR material of the first layer. Of course, the modified ELRI can take on any suitable formation or geometry.

[00707] In traditional integrated circuits, the RF antenna is implemented off the chip from controller functions because of parasitic losses. In contrast, with ELRI connecting the RF circuits directly to the RF antenna 3720, less parasitic losses tend to result, so that RF antenna 3720 can be implemented on the same chip with the RF circuits and digital circuitry of common devices.

[00708] Various implementations of the invention can produce one or more advantages which can be appreciated by one of ordinary skill in the art. For example, as just discussed, the use of ELRI can provide conductive capabilities that reduce or eliminate the penalty of parasitic losses due (e.g., due to interconnect resistance). As another example, because ELRI produces extremely low losses, RF circuitry can be devised and implemented that would be more cost effective and would otherwise be impractical. New RF products could also be developed that were not feasible with prior art technology, such as single chip RF transceivers with much higher Q, allowing handheld instruments to address a large number of separate channels. Certain implementations provide higher power efficiency due to reduced resistance losses. Some implementations will demonstrate increased sensitivity to analog and digital signals. There is the possibility of increased flexibility in placing system feature design elements. Further implementations will demonstrate increased signal fidelity. Still further implementations can show improved coordination between elements and increased information density within allocated band. Still other implementations enable new types of software and hardware logic that can be implemented on the ICs, or selective signal interference shielding.

[00709] Some implementations of the invention include an integrated circuit (IC) 3710 having RF components that can be implemented on the IC or the IC mounting substrate. The RF component can include subcircuits. As shown in Fig. 38-G, the subcircuits can include an RF amplifier 3810, an RF filter 3820, and an RF controller 3830 (and other subcircuits) interconnected through one or more conductive paths 3840 that include a modified ELRI having a first layer comprised of an ELR material and a second layer comprised of a modifying material bonded to the ELR material of the first layer. In accordance with various implementations, the first layer can include YBCO or BSCCO. The second layer can include chromium, copper, bismuth, cobalt, vanadium, titanium, rhodium, beryllium, gallium, or selenium. The interconnect can be comprised of multiple levels/layers of interconnect, some of which would ideally be composed of modified ELRI (or otherwise traditional metal), each being insulated from other adjacent levels by a

dielectric through which conductive vias are selectively placed to connect respective, continuous, conductive paths.

[00710] In some implementations, the RF component and RF antenna 3720 can be implemented on the same chip. For example, the IC mounting substrate can also include an RF antenna 3720 comprised of a first layer of the antenna comprised of ELR material and a second layer of the antenna comprised of modifying material bonded to the ELR material of the first antenna layer. As a result, the RF component does not require isolation through implementation on a separate chip.

[00711] In some implementations, a wireless device can be implemented including a power supply, a set of digital circuitry, and/or an RF transceiver utilizing ELRI technology. The wireless device can be any device or handheld transceiver that may use an RF transceiver or circuitry. Examples include, but are not limited to, a Wi-Fi device, a spread spectrum device, cell phones, wireless phones, a wireless USB device, a Bluetooth® device, a set of wireless earphones, a hearing aid, a medical transponder, a secure garage door opener, a radio frequency identification (RFID) tag, a remote security controller capable of adjusting a thermostat, or any security-conscious household, commercial, or industrial device within a property, a handheld computer interface, an automobile key transmitter, an RF interface security device, audio/video transceivers, and many others. The interfaced security devices can include universal remote security controllers to control property security (secure garage door opener, security alarm set/reset/inquiry, thermostat programming, general electrical control, etc.) and automobile key transmitters. In addition, the wireless device can be a handheld transceiver for special applications, like meter reading and inventory inquiries with special RFID tags, handheld computer interfaces (Bluetooth® program actuator and data transceiver) and the like.

[00712] The wireless devices which use the ELRI for RF circuitry can include a variety of improvements. For example, spread spectrum devices can be built with orders of magnitude more individual channels (e.g., 100 or more individual channels). In addition, cell phones, wireless phones, Bluetooth® devices, tablet and other computers, and other Wi-Fi devices will have greater reception/distance. In some cases, the reception/distance can be approximately an order of magnitude higher than the reception/distance available with traditional technology.

[00713] In some implementations, the RF transceiver can be coupled to the power supply and the set of digital circuitry. In some cases, the RF transceiver can be located

on the same chip as the digital circuitry. The RF transceiver can include an RF antenna 3720 coupled to the RF circuit. In accordance with various implementations of the invention, the RF circuit can include one or more subcircuits interconnected through one or more conductive paths 3730 and/or 3760 comprising a modified ELRI having a first layer comprised of an ELR material and a second layer comprised of a modifying material bonded to the ELR material of the first layer. In at least one implementation, the RF antenna 3720 can include a first ELR layer of the RF antenna comprised of ELR material and a second ELR layer of the RF antenna comprised of modifying material bonded to the ELR material of the first ELR antenna layer.

[00714] In present technology, monolithic microwave integrated circuits (MMICs) are only at the MSI & LSI levels of integration, because of the need to go off chip for passive devices capable of the higher frequencies. And, up to now, the cost of the semiconductor technology required for transistors capable of microwave frequencies has not been conducive to products requiring VLSI. In one or more implementations of the invention, ELRI can be used in passive elements of RF transmitter and receiver circuitry on an MMIC. By using the ELRI, MMICs can be created that integrate all functions on the same chip (e.g., the MMIC does not include off chip passive devices or interfaces) thereby transforming its capabilities. In some implementations, the MMIC can include a microprocessor, a microcomputer, a microcontroller, a DSP, a system on chip (SoC), a Disk Drive Controller, an ASIC, an ASSP, and/or an FPGA.

[00715] By using the ELRI material to implement passive elements and/or the conductive paths connecting RF circuits, the signals can propagate with a wave-front-delay time constant approaching zero. As a result, the delay of signals between the various functional elements can be eliminated or significantly reduced. In some implementations, the ELRI material used in the passive elements 3740 form very high Q transmitter and receiver circuits. ELRI for passive elements of high RF transmitter and receiver circuits will supply the passive elements, and the negligible resistance of the interconnect will enable microwave frequency circuits to create the capability of VLSI. Since all the RF circuits can be done on the MMIC, going one more step - an added microcontroller or DSP, in the same process, can transform its capability.

[00716] The very high-Q amplification (VHQA) that can be created by the use of the ELRI can enable transmission with much lower power, and much narrower bands at very high frequencies. This level of VHQA can be used in walky-talkies for personal communication in consumer products (in the 2.4 GHz range), in military usage in various

bands up to and beyond 100 GHZ, and in frequency hopping. In other implementations, the systems and methods can also be used for new metering and security data transmission, such as security sensor detections, and also in RADAR. In addition, very high frequency transceivers can be created for industrial and medical data transmission and controls in new high frequency bands.

[00717] Using this ELRI technology in an IC product synergistically favors utilizing other ELRI technologies. Examples include MEMS ELRI technologies such as ELRI for connecting MEMS circuits 3770 to an analog circuit on an IC 3710, ELRI for power supply distribution on an IC 3710, ELRI for 3D interconnects 3730 on an IC (which connects the IC to the mounting substrate 3750, through ELRI "3D" Interconnect 3730 on package 3750), and even ELRI for power supply distribution on a mounting substrate, all of which further improves the development of all ELRI technologies and especially improves the excellent performance of the RFIC product(s).

[00718] Various implementations of the invention provide for a MMIC made from a Monolithic semiconductor (e.g., silicon, GaAs, SiGe, GaN, SOS, SOI, etc.) or a multiple semiconductor monolithically constructed through "3 D" stacking or other novel manufacturing method, including MEMS on IC 3770 and/or MEMS on IC mounting substrate or SiP. The MMIC can include a set of ELRIs, an RF filter 3820 with one or more passive elements (e.g., laser programmable ELRI resistors 3910, and ELRI capacitors 3920 and 3740, an RF Oscillator 4090, an RF amplifier 3810, an RF controller 3830, and/or an RF antenna 3720, and other RF blocks 4030 and support blocks. The ELRIs, according to some implementations, can have a first layer comprised of an ELR material and a second layer comprised of a modifying material bonded to the ELR material of the first layer. In some implementations, the RF amplifier can be connected to the RF filter by the ELRIs. Similarly, the RF antenna 3720 can be connected to the RF amplifier 3810 by the ELRIs 3840, and the RF controller 3830 can be connect to the RF filter 3820 by ELRIs 3840.

[00719] In some implementations, the RF antenna 3720 has one or more conductive paths, in one or more levels of interconnect, that include a modified antenna ELRI having a first antenna layer comprised of ELR material (e.g., YBCO or BSCCO) and a second antenna layer comprised of modifying material (e.g., chromium, copper, bismuth, cobalt, vanadium, titanium, rhodium, beryllium, gallium, or selenium) bonded to the ELR material of the first antenna layer. In addition, the RF antenna 3720 may not require isolation from an RF controller 3830 through implementation on a separate chip.

[00720] The MMIC can be configured in various implementations to provide high frequency switching, microwave mixing, low noise amplification, or power amplification. The MMIC can also be configured to operate at microwave frequencies between, and including, 300 MHz and 300 GHz. In at least one implementation, the MMIC can operate at analog frequencies above 400 MHz. In some implementations, the MMIC can be part of a wireless device, such as those discussed above.

[00721] Traditional technology uses interconnects that are usually formed from Aluminum or Copper based metal. Unfortunately, these interconnects have parasitic resistance that limits the location of the embedded functions to such degree that timing becomes critical and in many cases prohibits some multiple functions, among other things. Moreover, because of the proliferation of parasitic resistance, loading embedded programs or parameter settings can be impaired or limited by the addition of even more resistance in the facilitation circuitry and therefore embedded RF functions are generally not offered. In contrast, various implementations of the invention provide for systems and methods using ELRI in embedded RF circuit functions on a semiconductor IC 3710. The use of ELRI reduces or eliminates the limitations found with the use of the traditional technology and enhances the implementation of RF circuits on an IC 3710.

[00722] In some of these implementations, the ELRI material can be used to implement the conductive paths for signals to propagate with a wave-front-delay time constant approaching zero. As a result, the delay of interface signals between the embedded RF circuit function(s) and the sub-systems enveloping the function(s), or between sub-system blocks connected to embedded function(s) can be significantly reduced or virtually eliminated. This makes these various blocks like virtual blocks, in the sense that each respective connecting signal seems to be touching its respective embedded node, so that it performs as the computer model indicates, with negligible parasitic variance, regardless of its actual physical location with respect to the embedded RF circuit function. In some implementations, the embedded RF circuit functions could be implemented on embedded microprocessors, microcomputers, microcontrollers, DSPs, SoC, ASICs, ASSPs, FPGAs, and any semiconductor IC with embedded functions of same or varying types.

[00723] Various implementations of the invention can provide one or more benefits. For example, by using ELRI routing in embedded RF function IC design, higher speed circuitry can be created, without significant skews between global signals, without the power lost due to buffering requirements in the present art. In addition, design

companies with sparse RF design experience could add RF circuits to their SoC. Moreover, many present RF function IC products could be redesigned to embed ELRI RF functions and achieve higher performance as well as lower power usage (e.g., operating voltage around, or less than, 0.25 Volts, and very low quiescent current in their Operational Amplifiers).

[00724] In some cases, embedded functions could be placed in locations on the IC that are more convenient to all aspects of the design. As a result, the development and design of the embedded RF functions could be less restrained, without requiring different customized interface buffers normally (in traditional technology) depending on most parasitic aspects of the enveloping SoC. Moreover, independent placement allowed by ELRI allows better "Con-current Engineering" in SoC development, since embedded functions could be designed more independently and solutions from a variety of sources could be more easily embedded. In some implementations, the embedded RF functions can become "Place & Route" cells, with accompanying embedded tool package (especially for design companies with sparse RF design experience).

[00725] In some instances, the decision to use ELRI for embedded RF circuits would favor the decision to use other applicable ELRI technologies. Examples include, but are not limited to ELRI for power supply distribution, ELRI for clock routing, or ELRI for SoC routing on an IC and to connect to the substrate, ELRI for 3D interconnects on an IC, ELRI for RF antenna on a mounting substrate, and/or others. Various cost functions can be utilized by designers to select the appropriate combinations to complete the RF product optimization.

[00726] Some implementations provide for an IC 3710 having an IC substrate, a set of circuitry 4010 (e.g., analog or digital circuitry) implemented on the IC substrate, and/or one or more programmable blocks 4020. The IC substrate can have one or more conductive paths in one or more layers of the substrate. The conductive paths can be comprised of an extremely low resistance interconnect (ELRI) having a first layer comprised of an extremely low resistance (ELR) material and a second layer comprised of a modifying material bonded to the ELR material of the first layer. A first programmable block can be connected to the set of circuitry through the one or more conductive paths. The first programmable block may include one or more components implemented on the substrate such as, but not limited to, a digital signal processor (DSP) 4035, an RF transmitter 4040 coupled to the DSP 4035; and/or an embedded core 4050 implemented on the IC substrate.

[00727] In accordance with some implementations, the embedded core 4050 can be programmable to perform one or more functions 4060. In various implementations, the embedded core 4050 can be a microprocessor, a microcomputer, a microcontroller, a GPU, a Data Flow Processor, or a DSP.

[00728] A set of programmable ELRI blocks comprising components (e.g., ELRI RF circuit 4070, ELRI RF antenna 4070, ELRI routing 4080, ELRI RF amplifier, an ELRI RF filter, an ELRI RF controller, etc) made from the ELRI can also be implemented on the IC substrate. Depending on the desired application, the ELRI blocks could be programmable at the design level, or field programmable, or programmable in software after the system is running. In some implementations, the IC with the embedded functions 4060 can be part of a wireless device, such as those discussed above.

[00729] Figure 41-G is a flow chart 4100 showing a set of exemplary operations for manufacturing RF circuitry, RF antennas, an MMIC with passive ELRI components, and/or embedded RF circuit functions using ERLI on an IC. The ELRI can be manufactured based on the type of materials, the application of the ELRI, the size of the component employing the ELRI, the operational requirements of a device or machine employing the ELRI, and so on.

[00730] In the implementations shown in Figure 41-G, a first depositing operation 4110 deposits a first layer of extremely low resistance (ELR) material on an IC. In accordance with various implementations, the first layer can comprise YBCO or BSCCO. A second layer comprised of a modifying material on the first layer of the ELR material, creating ELR interconnects is deposited during a second depositing operation 4120. The second layer can include chromium, copper, bismuth, cobalt, vanadium, titanium, rhodium, beryllium, gallium, silver or selenium. The material used as the first or base layer of an ELRI and/or the material used as a modifying layer of the ELRI may be selected based on various considerations and desired operating and/or manufacturing characteristics. Examples include, cost, performance objectives, equipment available, materials available, and/or other considerations and characteristics. Processing operation 4130 processes the ELR interconnects to form an RF antenna, a power distribution system, and/or a signal bus with one or more conductive paths capable of routing signals on the substrate.

[00731] In addition to the systems, devices, and/or applications described herein, one skilled in the art will realize that other systems, devices, and applications that include conductive paths may utilize the ELRIs described herein.

Part D – Integrated Circuit Routing

[00732] This section of the description refers to Figures 1-36 and Figures 37-H through Figure 43-H; accordingly all reference numbers included in this section refer to elements found in such figures.

[00733] Integrated circuit components, such as power distribution networks, clock distribution networks, and other signal distribution networks, that are formed of modified, apertured, and/or other new extremely low resistance (ELR) materials, are described. ELR material can be, for example, a film, a tape, a foil, or a nanowire. The ELR materials provide extremely low resistances to current at temperatures higher than temperatures normally associated with current high temperature superconductors (HTS), enhancing the operational characteristics of the integrated circuits at these higher temperatures, among other benefits. While various examples of the invention are described with reference to "modified ELR materials" and/or various configurations of modified ELR materials (e.g., modified ELR films, etc.), it will be appreciated that any of the improved ELR materials described herein may be used, including, for example, modified ELR materials (e.g., modified ELR material 1060, etc.), apertured ELR materials, and/or other new ELR materials in accordance with various aspects of the invention. As described herein, among other aspects, these improved ELR materials have at least one improved operating characteristic which in some examples, includes operating in an ELR state at temperatures greater than 150K.

[00734] Figure 37-H is a schematic diagram illustrating a cut-away view of a conductive path 3700 formed, at least in part, of a modified ELR film, such as a film having an ELR material base layer 3704 and a modifying layer 3706 formed on the base layer 3704. Various suitable modified ELR films are described in detail herein. As will be appreciated, the modified ELR film could have more than one ELR material layer, and/or more than one modifying layer, or can take on any other suitable configuration or geometry. Such a conductive path, when implemented in an integrated circuit, in multiple levels of interconnect, insulated between themselves except for particular connecting vias designed to respectively connect each of the continuous conducting paths, using the levels to arrange convenient density and connectivity, which can be used, for example, for distributing power and propagating signals between circuit components in microprocessors, microcomputers, microcontrollers, digital signal processors, SoCs, disk

drive controllers, memories, ASICs, ASSPs, FPGAs, or practically any other semiconductor integrated circuit that can be made compatible with modified ELR films.

[00735] As shown in the example of Figure 37-H, the conductive path includes an ELR material base layer 3704 and a modifying layer 3706 formed, through any suitable process, on the base layer 3704. The conductive path can be formed on a substrate 3702, for example, the dielectric substrate of an integrated circuit. Being formed of a modified ELR film, the conductive path 3700 provides little or no resistance to the flow of current in the conductive path under suitable circumstances, such as at temperatures higher than those used in conventional HTS materials, such as room or ambient temperatures (~21C).

[00736] The material or dimensions of the substrate 3702 may be selected based on a variety of factors. For example, selecting a substrate material having a higher dielectric constant will generally reduce capacitance seen by a transmission line, and thus decrease the power necessary to drive a signal. One skilled in the art will appreciate the substrate may be formed of a number of different materials and into a number of different shapes in order to achieve certain desired properties and/or operating characteristics.

[00737] In some examples, the modified ELR conductive path provides extremely low resistance to the flow of current at temperatures between the transition temperatures of conventional HTS materials (~80 to 135K) and room temperatures (~294K). In these examples, the conductive path may include a cooling system (not shown), such as a cryocooler or cryostat, used to cool the conductive path 3700 to a critical temperature for the type of modified ELR film utilized for the conductive path 3700. For example, the cooling system may be a system capable of cooling the conductive path to a temperature similar to that of liquid Freon, to a temperature similar to that of frozen water, or other temperatures discussed herein. That is, the cooling system may be selected based on the type and structure of the modified ELR film utilized for the conductive path 3700.

[00738] Figure 38-H is a diagram, which represents an example model of a conductive path formed from a modified ELR film. In some examples, the model includes an input "I" and an output "O." R_I and R_O correspond to the respective resistances of the connecting materials on the input and output end of conducting path formed from the modified ELR film. R_{V1}, R_{V2}, R_{V3}, and R_{V4} correspond to resistances of vias and/or other connections of the outer skin to the conducting path. R_{W1} and R_{W2} correspond to the resistances of the internal path of the modified ELR film. R_{S1}–R_{S4}, and C_{S1}–C_{S5} correspond to the transmission line model of the outer skin of the conducting path. The elements

encompassed by the dashed line 3802 can be serially duplicated at position P for each via (or other connection) on the conducting path. The example of Figure 38-H shows a branch B_1 which connects to a conductive via (represented by R_{V4}) and the output O destination series path. In some examples, the model can include more elements including inductors.

[00739] Due to the extremely low resistance of a conductive path formed from a modified ELR film, a signal propagating on the conductive path has a wave-front-delay time constant approaching zero, thereby minimizing drive strength requirements, which reduces power consumed. Because a signal propagates through the crystalline structure of a modified ELR film, in a manner analogous to that of a waveguide, unencumbered by the capacitance of the outside environment, the signal tends to achieve minimal delay. However, the signal also propagates on the outside skin of the modified ELR film which experiences normal resistance and the capacitance of the surrounding environment. Thus, the signal propagating through the crystalline structure of the modified ELR film can reach the destination node and change the voltage of the node before the outside skin has completely achieved its changed voltage.

[00740] A reduction in drive strength requirements can also lead to a reduction in the transistor sizes that drive signals over conductive paths formed of modified ELR material. Having smaller transistor sizes can reduce the silicon area needed for the integrated circuit layout allowing for further miniaturization of integrated circuits and for circuits that perform more efficiently. Another benefit of conductive paths formed from modified ELR material is the reduction of the encumbrance or significance of the timing constraints in circuit design due to the reduced delay in the propagation of signals.

[00741] As discussed herein, many integrated circuit devices and systems may utilize, employ and/or incorporate modified ELR conductive paths that exhibit extremely low resistances at high or ambient temperatures. That is, virtually any device or system that provides a path for a current of electrons may incorporate the modified ELR conductive paths as described herein. The following section describes a few example devices, systems, and/or applications. One of ordinary skill will appreciate that other devices, systems, and/or applications may also utilize the modified ELR conductive paths, while there are some peculiar and novel advantages which might not seem obvious without due considerations.

[00742] In some examples, a power supply distribution network of an integrated circuit can utilize the modified ELR conductive paths as described herein. Figure 39-H is a

diagram of an example power distribution network 3900 formed of modified ELR conductive paths. As shown in Figure 39-H, modified ELR material is used to implement the conductive paths, such as conductive path 3902, for voltage supplies (V_1-V_4) and ground (G) connections to be distributed around the integrated circuit with distributed voltage decreases approaching zero due to the low resistance of the modified ELR material. Since, in some examples, a modified ELR conductive path can be directional, i.e., current flows along a particular plane of the modified ELR material, the power supply distribution network 3900 of Figure 39-H utilizes two substantially orthogonal layers coupled together by vias, such as via 3904, to route power through the integrated circuit.

[00743] The power distribution network of a conventional integrated circuit is divided into several power domains, each having a particular voltage utilized by components of the integrated circuit. In conventional integrated circuits, i.e., circuits employing metallic conductive paths, each power domain typically has its own conducting layer because of the resistive materials used for the conductive paths. These traditional conductive paths have a significant amount of resistance resulting in power loss, through heat (I^2R) and through larger or extra transistors used in attempt to mitigate the propagation delays caused by resistance. The "brute force" required to drive resistive signal lines causes noise on the power distribution conductors, which must be decoupled. And in many cases, separate voltage domains are designed-in to separate particularly noisy circuits. However, because of the excellent conductivity of modified ELR material, in an integrated circuit that employs modified ELR conductive paths, all voltage and ground domains can be routed in the two orthogonal layers as shown in Figure 39 without additional layers necessary. For example, voltages V_1, V_2, V_3, and a ground network can all be distributed over the integrated circuit using the two-layer power distribution network 3900 of Figure 39-H.

[00744] Many other advantages come from using conductive paths formed from modified ELR material. For example, a power distribution network using modified ELR materials not only reduces power dissipation, but also reduces the "IR Drop" to negligible amounts, which in turn allows for lower operating voltage. This lower operating voltage reduces parasitic leakage of the transistors, thus improving overall circuit efficiency. Also, because of the extremely fast propagation of signals in mELR, noise pulses on the power distribution network get immediately propagated to all distributed decoupling capacitances. And when modified ELRI is used for routing signals, "brute force" drivers are not required, so there are much less noise violations.

[00745] A power supply distribution network formed from modified ELR conductive paths can be implemented on, for example: microprocessors, microcomputers, microcontrollers, DSPs, SoC, disk drive controllers, memories, ASICs, ASSPs, FPGAs, and virtually any other semiconductor integrated circuit that can be made compatible with modified ELR films or materials.

[00746] In some examples, a clock distribution network of an integrated circuit can utilize the modified ELR conductive paths as described herein. Figure 40A-H is a diagram of an example clock distribution network formed of modified ELR conductive paths. Figure 40A-H includes a clock driver 4002 coupled with a trunk path 4004 of the clock distribution network. As shown in Figure 40A-H, a clock distribution network formed from modified ELR conductive paths can distribute a clock signal from the clock driver 4002 to clocked components of the integrated circuit, such as gate 4006. The trunk path 4004 is coupled with substantially perpendicular branch paths, for example, branch path 4008, which distribute a clock signal to integrated circuit components. The clock distribution network of Figure 40A-H also includes parallel branch paths, such as branch path 4010 which can further distribute clock signal to other circuit components. The branch paths 4010 can be coupled with the trunk path 4004 through vias, such as via 4012, connecting substantially orthogonal layers.

[00747] One advantage of using modified ELR conductive paths is that clock signals propagating over such a network have a wave-front-delay time constant approaching zero, without the need for extra buffer circuits or delay circuits, thereby minimizing propagation delay and clock skew between synchronous circuits.

[00748] Figure 40B-H is a diagram of an alternative layout illustrating a clock distribution network formed of modified ELR conductive paths. As shown in Figure 40B-H, the clock distribution network has one central trunk 4054 coupled with a clock driver 4052 to feed perpendicular branches, such as branch 4056, which, in turn, feed clock buffers to clocked components, such as gate 4058. Since, in one implementation, a modified ELR conductive path can be directional, e.g., current flows along a particular plane of the modified ELR material, the clock distribution network of Figures 40A-H and 40B-H utilize two substantially orthogonal layers connected together by vias, such as vias 4012 and 4060, to route a clock signal through the integrated circuit.

[00749] Figure 40C-H is a diagram of an alternative layout illustrating a clock distribution network formed of modified ELR conductive paths. As shown in Figure 40C-H, the clock distribution network has one central trunk 4074 coupled with a clock driver 4072 to feed

perpendicular branches, such as branch 4076, which, in turn, feed through the geometric progression H-structure of the clock distribution network to clocked components, such as gate 4078. Since, in one implementation, a modified ELR conductive path can be directional, e.g., current flows along a particular plane of the modified ELR material, the clock distribution network of Figures 40A-H, 40B-H, and 40C-H utilize two substantially orthogonal layers connected together by vias, such as vias 4012, 4060, and 4080 to route a clock signal through the integrated circuit.

[00750] Some advantages of using modified ELR material for conductive paths of a clock distribution network include, for example, a significant reduction in power and speed losses from a convention resistive network due to buffering and the added capacitance of widening conductive paths to reduce resistance. Further, clock skew and insertion delay are appreciably reduced, thus reducing the encumbrance or significance of the design constraints. Similarly, multi-phase clock architectures can be implemented and still run synchronously due to the greatly reduced clock skew. Additionally, there are some sophisticated synchronous integrated circuit architectures, which do not require a clock signal to be propagated. These circuits use special software to assure their synchronicity. These circuits can utilize modified ELR conductive paths in their synchronous control signals, as though they were clocks, to realize similar advantages.

[00751] A clock distribution network formed from modified ELR conductive paths can be implemented on, for example: microprocessors, microcomputers, microcontrollers, DSPs, SoC, disk drive controllers, memories, ASICs, ASSPs, FPGAs, and virtually any other semiconductor integrated circuit that can be made compatible with modified ELR films or materials.

[00752] In some examples, analog components of an integrated circuit can be coupled with a compensating circuit using modified ELR conductive paths as described herein. Figure 41-H is a block diagram illustrating analog components coupled with compensation circuits by modified ELR conductive paths. Example block diagram of Figure 41-H includes analog components, for example, amplifiers, such as amplifier 4102, which are coupled with compensation circuits 4104 and 4106. As described previously, in one implementation, a modified ELR conductive path can be directional, e.g., current flows along a particular plane of the modified ELR material. Thus, in the example of Figure 41-H, the conductive paths used to couple to the compensation circuits with the analog components can be implemented using two substantially

orthogonal layers, for example 4110 and 4112, connected together by vias, such as via 4108, to route signals through the integrated circuit.

[00753] Analog circuits are typically more sophisticated and useful when provided compensation signals from compensation circuits. However, conventional conductive paths, for example aluminum or copper, introduce significant resistance, which degrades compensation signals and reduces overall system performance. One advantage of using modified ELR conductive paths to propagate signals between analog components and compensation circuits is, with a time constant approaching zero, the resistance interference in the compensation process is minimized.

[00754] Additionally, conventional integrated circuits including analog components are typically orientation sensitive, i.e., must be spatially balanced. If the circuit is unbalanced, the resistance in the conductive paths degrades performance and functionality. Implementing conductive paths formed of modified ELR material, with reduced resistance, alleviates most of the problem of location of individual analog components and integrated circuits. This allows for other considerations, for example, space considerations, to be taken into account when designing a circuit.

[00755] In some examples, conductive paths of memories can be implemented using modified ELR films as described herein. For example, Figure 42-H is a block diagram of an example memory implementing conductive paths with modified ELR conductive paths. In the example of Figure 42-H, the memory uses modified ELR conductive paths for a low-threshold, high-speed memory "read" function. Each memory cell 4202 is coupled with bit lines 4204 and 4206, and an address line, such as line 4210, through vias, such as via 4208. The bit lines 4204 and 4206 are coupled with a sensing amplifier 4212 to enable low voltage sensing of the bit lines.

[00756] The speed and accuracy of a semiconductor memory is based on the sensing of a voltage of the memory cell. In some examples, a pair of bit lines is connected to all cells on a particular row of cells. When the column select line, for example, line 4210, is enabled, the complementary outputs of the memory cell 4202 on the selected column connect to the respective bit lines 4204 and 4206. As the transistors of the memory cell drive the bit lines 4204 and 4206, the sensing amplifier 4212 provides an output as soon as it can distinguish which bit line is high and which is low. The time it takes to charge the lines, such that the sensing amplifier can detect a difference, can be compromised in traditional technology, with its resistive interconnect, by the designed size of the cell (smaller cells produce smaller drive) and length of the row (longer rows cause more

resistive-capacitive load for the memory cell to drive). However, bit lines formed from modified ELR films allow the transistors of the memory cell to drive the sensing amplifier input immediately toward the stored voltage levels thereby requiring only minimal power to sense and respond to these bit lines at a much quicker sample rate.

[00757] Memory sensing amplifiers are designed for a particular semiconductor technology and particular memory row lengths. Conventional memories have limited row lengths, and therefore smaller blocks, due to parasitic resistance. In order to achieve faster read times, conventional memories use higher quiescent currents such that the sensing amplifier reacts faster without waiting for the memory cell to drive the resistive bit lines to a different logic state. Thus, conventionally, faster memories equate to higher power usage. Because of the reduced effect resistance and capacitance a signal encounters as it propagates inside a modified ELR film's structure, the memory can produce faster and more accurate reads in the sensing amplifier with lower power usage. Further, bit lines formed from modified ELR films would allow for much larger blocks and still use much less power and achieve much higher performance.

[00758] In some examples, a data bus and instruction lines in a data flow processor can be implemented using modified ELR conductive paths as described herein. Figure 43-H is a block diagram of an example function cell of a data flow processor 4300 with conductive paths formed from modified ELR material. The data flow processor includes a function cell 4302, a data bus 4306, and an instruction line 4304. The data bus 4306 and the instruction line 4304 can be implemented using a modified ELR film as described herein.

[00759] To define the limit of its performance, a processor built according to a dataflow architecture depends on the speed of the instruction signals propagating on an instruction line to execute a function and then data signals propagating on the data bus. Implementing a bus and instruction lines with a modified ELR film causes a signal to have a wave-front-delay time constant approaching zero, thereby minimizing drive strength requirements, which reduces power. Further, due to reduced propagation delay, instruction signals would practically instantaneously engage the functions, and data signals would instantaneously propagate to their instructed destination.

[00760] Conventional data flow processor operation frequency is limited by propagation delay in the data bus and instruction lines caused by resistance of conventional conductors. Implementing the conductors with modified ELR materials provides several orders of magnitude faster performance of the instruction lines and data bus, where an

array of interconnects is strategic in implementing the architecture. For example, DSP applications could process several orders of magnitude faster frequencies, RF receivers could demodulate higher RF transmission bands, and DSPs could implement more sophisticated algorithms (i.e., with greater number of instructions) in the same time span as a processor using conventional conductors can achieve.

[00761] In some examples, some or all of the systems and devices describes herein may employ low cost cooling systems in applications where the specific modified ELR materials utilized by the application exhibit extremely low resistances at temperatures lower than ambient temperatures. As discussed herein, in these examples the application may include a cooling system (not shown), such as a system that cools a modified ELR conductive path to a temperature similar to that of liquid Freon, to a temperature similar to that of frozen water, or other temperatures discussed herein. The cooling system may be selected based on the application, and/or the type and structure of the modified ELR film or material utilized by the application.

[00762] In addition to the systems, devices, and/or applications described herein, one skilled in the art will realize that other integrated circuit systems, devices, and applications may utilize the modified ELR conductive paths described herein. Additionally, when terms such as "film" or "material" are used herein, it should be apparent that other structures or implementations are possible and within the scope of the claimed invention.

Part E – Integrated Circuit SiP Devices

[00763] This section of the description refers to Figures 1-36 and Figures 37-I through Figure 41B-I; accordingly all reference numbers included in this section refer to elements found in such figures.

[00764] Various implementations of the invention generally relate to extremely low resistance interconnects (ELRI), such as ELRI incorporating modified, apertured, and/or other new ELR materials. In some implementations, the ELRI can have a first layer comprised of an extremely low resistance (ELR) material and a second layer comprised of a modifying material bonded to the ELR material of the first layer. The ELRI can be used in a variety of systems and methods to create various improvements. Some examples where the various efficiencies are created include, but are not limited to, systems and methods for a radio frequency antenna on an IC mounting substrate, power supply distributions on a semiconductor IC mounting substrate and system-in-package

(SiP) substrate, and signal (e.g., control, clock, data and other signal types) routing on a semiconductor mounting substrate.

[00765] For example, when an ELRI material is used to implement the conductive paths for RF antenna topologies on an IC mounting substrate, the required area tends to be less than conventional substrate topologies that do not use ELRI material. In addition, the RF antenna can be located in isolated locations without incurring the penalty of interconnect resistance, thereby yielding higher Q capability. As such, the RF antenna topologies resulting from the use of ELRI material in the conductive paths may require less active circuits and thus less semiconductor area for the various circuits.

[00766] In some implementations, an ELRI material can be used to implement the conductive paths for voltage supplies (including multiple voltage domains) and ground connections to be routed as busses to multiple parts of the substrate. These paths form virtual nodes, since the distributed voltage variations approach zero. Furthermore, all high frequency incidental noise spikes on power distribution conductors near instantaneously travel to all decoupling capacitances where they are dampened.

[00767] In addition to providing conductive paths for voltage supplies, ELRI material can be used for routing control, clock, data and other signals on an IC Mounting Substrate (or SiP Substrate). The ELRI material provides extremely low-resistance conductive paths for the signals. In some implementations, the conductive paths can be routed on a pair or pairs of substantially orthogonal directional layers (insulated between themselves except for designed conductive vias) to connect to IC Pads, substrate pins, or any other component in the package.

[00768] The ELRI can be manufactured based on the types of materials, the application of the ELRI, the size of the component employing the ELRI, the operational requirements of a device or machine employing the ELRI, and so on. As such, during the design and manufacturing, the material used as a base layer of a ELRI and/or the material used as a modifying layer of the ELRI may be selected based on various considerations and desired operating and/or manufacturing characteristics.

[00769] Figure 37-I is diagram illustrating the use of ELRI materials implementing the conductive paths for RF antennas 3710 on a mounting substrate 3750. In traditional integrated circuits, the RF antenna is implemented off the chip from controller functions because of parasitic losses. In contrast, with ELRI connecting the RF circuits in IC 3730 directly to the RF antenna 3710, less parasitic losses are encountered, so that RF

antenna 3710 can be implemented on the mounting substrate 3750 of the same chip with the RF circuits and IC 3730.

[00770] In accordance with various implementations of the invention, when an ELRI material is used to implement the conductive paths for RF antenna topologies on a mounting substrate 3750, the required area is less than in conventional substrate topologies. In addition, the RF antenna 3710 can be in isolated locations without incurring the penalty of interconnect resistance, thereby yielding higher Q capability with the passive parasitics. As such, the RF antenna topologies resulting from the use of ELRI material in the conductive paths require less active circuits and thus less semiconductor area for various circuits.

[00771] Various implementations of the invention can produce one or more advantages which can be appreciated by one of ordinary skill in the art. For example, as just discussed, the use of ELRI can provide conductive capability that allows antenna topologies in typically less area than conventional substrate topologies and in isolated locations without incurring the penalty of interconnect resistance. As another example, because ELRI has extremely low losses, RF antenna architectures can be devised and implemented that would be more cost effective and practical. In some implementations, the RF antenna design could even significantly reduce the active circuit amplification and filtering. ELRI also enables the design to implement RF antenna connected more closely to RF circuitry on the IC with improved conductive interconnect, with less parasitic losses yielding higher Q, such that it can achieve its design requirements without special semiconductor processes and without going off the IC's mounting substrate package. New RF products could also be developed that were not feasible with prior art technology, such as single chip RF transceivers with much higher Q, allowing handheld instruments to address a large number of separate channels.

[00772] In accordance with various implementations, RF antenna 3710 can be implemented with microprocessors, microcomputers, microcontrollers, computer memory, DSPs, SoC, Disk Drive Controllers, ASICs, ASSPs, FPGAs, neural networks, MEMS, MEMS arrays, micro energy storage devices, and for any other IC mounting substrate implementing RF circuit antennas 3710. As illustrated in Fig. 37-I, some implementations of the invention provide for an integrated circuit (IC) comprising an IC mounting substrate 3750, an RF antenna 3710, and an RF circuit 3730. The IC mounting substrate 3750 can have multiple layers and one or more conductive paths 3720 and 3740 for signal routing. The one or more conductive paths 3740 can be made of a

modified extremely low resistance interconnect (ELRI) having a first layer comprised of an extremely low resistance (ELR) material. In addition, the one or more conductive paths 3720 and 3740 can also have a second layer comprised of a modifying material bonded to the ELR material of the first layer.

[00773] The radio frequency (RF) antenna 3710 can be implemented on the IC mounting substrate 3750. The RF circuit 3730 can also be implemented on the IC mounting substrate 3750 and connected to the RF circuit 3730 through the ELRI. In some cases, the RF antenna 3710 can be in close proximity to the RF circuit 3730 when compared to requirements for similar implementations without the ELRI. In some implementations, the RF antenna can include a first layer comprised of ELR material and a second layer comprised of modifying material bonded to the ELR material of the first layer.

[00774] In accordance with some implementations, a wireless device can include a power supply coupled to an RF transceiver using various configurations of ELRI. In accordance with various implementations, the RF transceiver can include a mounting substrate, an RF antenna, and an RF circuit. The mounting substrate can have one or more conductive paths (3720 and 3740). In some cases, the one or more conductive paths can be comprised of extremely low resistance interconnects (ELRI) having a first sub-layer comprised of an extremely low resistance (ELR) material and a second sub-layer comprised of a modifying material bonded to the ELR material of the first layer. The RF antenna can be implemented on the mounting substrate along with the RF circuit. The RF antenna can be connected to the RF circuit through the ELRI. In some implementations, the RF antenna includes a first layer comprised of ELR material and a second layer comprised of modifying material bonded to the ELR material of the first layer.

[00775] The wireless devices can be any device or handheld transceiver. Examples include, but are not limited to spread spectrum devices, cell phones, wireless phones, Bluetooth®, Wi-Fi, and Wi-Max devices, interfaced security devices, earphones, hearing aids, medical transponders, and many others. The interfaced security devices can include universal remote security controllers to control property security (secure garage door opener, security alarm set/reset/inquiry, thermostat programming, general electrical control, etc.) and Automobile key transmitters. In addition, the wireless device can be a handheld transceiver for special applications, like meter reading and inventory inquiries with special RFID tags, handheld computer interfaces (Bluetooth® program actuator and data transceiver) and the like.

[00776] The wireless devices which use the ELRI for RF antenna include a variety of improvements. For example, spread spectrum devices can be built with orders of magnitude more individual channels (e.g., 100 or more individual channels). Cell phones and Wireless phones, Bluetooth® device, and other Wi-Fi devices will have approximately an order of magnitude greater reception/distance.

[00777] Figure 38-I is flow chart showing a set of exemplary operations 3800 for designing a radio frequency antenna using ELRI material. In accordance with the implementations illustrated in Figure 38-I, receiving operation 3810 receives a set of design requirements for an RF transceiver. The design requirements can include an RF antenna implemented on an integrated circuit (IC) mounting substrate and an RF circuit implemented on the IC mounting substrate. In addition, the cost of various materials, types of available materials, location restrictions/requirements for various components, manufacturing methodologies, component size, range, Q factor, power requirements, and other design requirements can be included. For example, in one implementation, the design requirements can include that the RF antenna is in close proximity to the RF circuitry.

[00778] Generation operation 3820 produces a design by routing one or more conductive paths on the IC mounting substrate to connect the RF antenna to the RF circuit. The conductive paths can include extremely low resistance interconnects (ELRI) with a first layer comprised of an extremely low resistance (ELR) material and a second layer comprised of a modifying material bonded to the ELR material of the first layer. Generation operation 3820 takes into account the extremely low resistance interconnects and the affect on the various design requirements.

[00779] Verification operation 3830 verifies that the set of design requirements are met. If verification operation 3830 determines that the design is not met, an additional design iteration is performed by branching to generation operation 3820. Once verification operation 3830 determines the set of design requirements are met, the design is submitted for fabrication by branching to fabrication operation 3840.

[00780] On IC mounting substrates, such as BGA and PGA, there are often buses for power supply distribution. The conduction paths are commonly joined to reduce resistance from the external power source to any individual IC power pad. The resistances on traditional designs are still significant and limit the performance of the IC. In addition, on board an IC, multiple voltage domains are typically created to separate the resistance from the voltage supply node of various blocks in the conductive path

connecting to the external power source. Moreover, the resistance causes distributed voltage "IR Drop" triggering iterative mitigation remedies of circuit design, including splitting into multiple voltage domains with the same voltage (to keep the noise in one block from affecting another block). In addition, noise cannot be dampened when resistance is so pervasive, so the mitigation is to keep lines separate until a more conductive connection to the external source.

[00781] In accordance with various implementations, ELRI can be used for power distribution. ELRI routing reduces the power dissipation (caused by running current through the resistance of the substrate lines), in addition to making the "IR Drop" negligible making multiple voltage domains and ground busses on the substrate "Virtual External Power Supply" nodes. Eliminating "IR Drop" on the lines allows connecting power and ground nodes on the mounted IC to be bonded to the virtual nodes on the substrate, in some cases reducing the number of pads.

[00782] Figure 39-I is an example layout diagram illustrating a power supply distribution 3900 using ELRI on a substrate. ELR power distribution provides multiple voltage domains and ground connections with voltage differences approaching zero at various points on the lines, so each IC Power Supply Pad would bond to a "Virtual External Power Supply" for each given voltage.

[00783] In some implementations, an ELRI material can be used to implement the conductive paths for voltage supplies (including multiple voltage domains) and ground connections to be routed as buses throughout the layout. These paths form virtual nodes, since the distributed voltage variations approach zero. Furthermore, all high frequency noise spikes instantaneously travel to all decoupling capacitances where they are dampened or de-coupled. In accordance with various implementations, the conductive paths can be on any IC Mounting Substrate or SiP Substrate, such as a BGA or PGA substrate for single ICs, or a SiP or MCM substrate, or even Thin Film Passive Component substrate or for any system with one or more components on the substrate.

[00784] Some implementations of the invention provide for an IC package 3910 comprising a substrate, a power bus 3920, and one or more virtual nodes coupled to a pad 3930. The substrate can be a BGA substrate, a PGA substrate, an SiP substrate, an MCM substrate, or a thin film passive component substrate. Power bus 3920 can include one or more conductive paths having a low resistance resulting in a negligible IR drop for power distribution implemented on the substrate. The one or more conductive paths include a first layer comprised of an extremely low resistance (ELR) material and a

second layer comprised of a modifying material bonded to the ELR material of the first layer. The one or more virtual nodes formed by ground connections routed around the substrate, wherein each ground connection includes a second ELR material and a second modifying material bonded to the second ELR material

[00785] In some implementations, the one or more conductive paths can be arranged to form multiple voltage domains. The IC package 3910 can also include one or more virtual external power supply nodes created from the multiple voltage domains and ground connections. The IC package can include a set of extremely low resistance interconnects (ELRI) 3950 and an integrated circuit connected to the virtual external power supply nodes via one or more ELRI in the set of ELRI. The integrated circuit can, in some implementations have a low voltage circuit with an operating voltage of approximately 0.25 volts or less. In some implementations, the IC package 3910 can have multiple layers and have a multi-layer power distribution within the multiple layers as shown by 3960. In some implementations, the IC package 3910 can also include a set of wire bonds 3940 and one or more integrated circuits connected to the virtual external power supply nodes via one or more wire bonds 3940 in the set of wire bonds.

[00786] Various implementations of the invention include a circuit with a voltage supply, one or more integrated circuits, and an IC package 3910 with a power supply distribution to supply power from the voltage supply to the one or more integrated circuits. The IC package 3910 can include a substrate, a power bus 3920 and one or more virtual nodes. In accordance with various implementations, the substrate can be a BGA substrate, a PGA substrate, a SiP substrate, an MCM substrate, a thin film passive component substrate, or other. The power bus 3920 can have one or more conductive paths with a low resistance for power distribution implemented on the substrate and may form multiple voltage domains with virtual external power supply nodes. The low resistance in the conductive paths results in a negligible IR drop. In some implementations, the IC package 3910 can include multiple layers 3960 allowing a multi-layer power distribution within the multiple layers 3960.

[00787] The one or more conductive paths can include a first layer comprised of an extremely low resistance (ELR) material and a second layer comprised of a modifying material bonded to the ELR material of the first layer. The one or more virtual nodes can be formed by ground connections routed around the substrate. Each ground connection can include a second ELR material and a second modifying material bonded to the second ELR material.

[00788] In some implementations, the circuit includes a set of ELRI coupling the one or more integrated circuits to the virtual external power supply nodes via the set of ELRI. In other cases, the circuit can include a set of wire bonds 3940 coupling the one or more integrated circuits to the virtual external power supply nodes via the set of wire bonds 3940.

[00789] As will be appreciated by one or ordinary skill in the art, using ELRI for power distribution on a substrate provides new packaging methods and materials to significantly reduce noise and power usage on redesign of existing products that use ICs. The use of ELRI would also improve analog circuit design on ICs, because power supply margins would be supplied to IC Pads under tight, dependable control. In addition, the use of ELRI creates the possibility of new products that were unfeasible in prior art technology. For example, some analog circuits on ICs with digital circuits that do not work together in present technology because voltage margins cannot be delivered to the IC pad, would be feasible within the paradigm of the invention. Another example includes novel circuits and circuit architectures that would become feasible with lower power. In other cases, ICs could use power usurped from ambient environment, by utilizing ELRI for RF antenna on a mounting substrate with connections to the IC. Other examples include, very-low voltage circuits (in the 0.25 V operating range or less), which require extremely-low-voltage-drop packaging. A yet another examples include, reconfigurable ICs with MEMS switches controllable by sensors and/or logic elements, implemented in hardware and/or software.

[00790] In addition to providing conductive paths for voltage supplies, ELRI material can be used for routing signals on an IC Mounting Substrate (or SiP Substrate). The use of ELRI improves the quality of interconnection (over present art) by providing signal paths with near-zero resistance. In some implementations, the conductive paths can be routed on a pair or pairs of orthogonally directional layers to connect to IC Pads, substrate pins, or any other component in the package. In many cases, the use of ELRI material for signal routing would reduce the design time by eliminating iterative mitigation design remedies that are presently required because of the timing problems caused by the resistance of present art technology. The use of ELRI material might also allow margins for more ICs or other components on the substrate than would otherwise meet design requirements using present art technology.

[00791] Various implementations of the invention include an IC package comprising a substrate having a set of components (e.g., substrate pins, low voltage IC's, etc) and any

required conductive paths. In accordance with various implementations, the substrate can be a BGA substrate, a PGA substrate, an SiP substrate, an MCM substrate, a thin film passive component substrate, or other. The IC package may have multiple layers allowing the one or more conductive paths to be routed on a pair or pairs of orthogonal directional layers separated by an insulator with particular connecting vias designed to respectively connect all continuous conducting paths.

[00792] The one or more conductive paths provide interconnections between the set of components and can include extremely low resistance (i.e., near-zero resistance) interconnects for routing signals on the substrate. According to some implementations, the extremely low resistance interconnects include a first layer comprised of an extremely low resistance (ELR) material and a second layer comprised of a modifying material bonded to the ELR material of the first layer.

[00793] Some implementations include a circuit having a voltage supply, one or more integrated circuits (e.g., with a reduced power output driver), and an IC package. The IC package can have a set of components (e.g., IC pads, substrate pins, etc) interconnected by a set of signal routing paths that transfer signals between the voltage supply and the one or more integrated circuits. The IC package can include a substrate and a signal bus. The signal bus can have one or more conductive paths for signal routing on the substrate. In some implementations, the one or more conductive paths include extremely low resistance (e.g., near-zero) interconnects having a first layer comprised of an extremely low resistance (ELR) material and a second layer comprised of a modifying material bonded to the ELR material of the first layer. In some implementations, the substrate can include an RF antenna with a first layer of the RF antenna comprised of ELR material and a second layer of the RF antenna comprised of modifying material bonded to the ELR material of the first layer of the RF antenna.

[00794] As will be appreciated by those of ordinary skill in the art, traditional interconnects result in distributed voltage “IR Drop”, triggering iterative mitigation remedies of circuit design, including more layers on the substrate to route signals and reduce the noise between lines. In addition, noise cannot be dampened when resistance is so pervasive, so the most common mitigation is to keep lines separate and isolated from each other, which utilizes more routing resources. Various implementations of ELRI routing reduce the power dissipation caused by running current through the resistance of the substrate lines, in addition to reducing the signal’s voltage “IR Drop” to a negligible amount, reducing the wasted power of the IC signal output driver.

[00795] Various implementations utilize ELRI for routing signals on an IC mounting substrate. The use of ELRI for routing signals will result in new packaging methods and materials to significantly reduce noise and power usage on redesign of existing products that use ICs. Moreover, using ELRI to route signals would improve analog circuit design on ICs, because signal margins would be delivered to IC Pads under tight, dependable control. In addition, using ELRI for signal routing would allow for the creation of new products that were unfeasible in prior art technology. Examples include, but are not limited to, analog circuits on ICs with digital circuits that do not work together in present technology because voltage margins cannot be delivered to the IC pad. New novel circuits and circuit architectures would become feasible with lower current, lower power, and tighter margins. ICs could use power harvested from ambient environment, by utilizing ELRI for RF antenna on a mounting substrate, with connections to the IC. Other examples include the use of very-low voltage circuits (in the 0.25 V operating range or less), which require extremely-low-voltage-drop packaging.

[00796] Figure 40-I is a flow chart 4000 showing a set of exemplary operations for manufacturing an RF antenna, a power distribution system, and/or a signal bus using ERLI on a substrate. The ELRI can be manufactured based on the type of materials, the application of the ELRI, the size of the component employing the ELRI, the operational requirements of a device or machine employing the ELRI, and so on.

[00797] In the implementations shown in Figure 40-I, a first depositing operation 4010 deposits a first layer of extremely low resistance (ELR) material on a substrate. In accordance with various implementations, the first layer can comprise any suitable material such as YBCO or BSCCO. A second layer comprised of a modifying material on the first layer of the ELR material, creating ELR interconnects, is deposited during a second depositing operation 4020. The second layer can include any suitable material such as chromium, copper, bismuth, cobalt, vanadium, titanium, rhodium, beryllium, gallium, silver or selenium. The material used as the first or base layer of an ELRI and/or the material used as a modifying layer of the ELRI may be selected based on various considerations and desired operating and/or manufacturing characteristics. Examples include, cost, performance objectives, equipment available, materials available, and/or other considerations and characteristics. Processing operation 4030 processes the ELR interconnects to form an RF antenna, a power distribution system, and/or a signal bus with one or more conductive paths capable of routing signals on the substrate.

[00798] In some examples, conductive paths formed from modified ELR materials can be used in packaging integrated circuits. For example, Figure 41A-I is a block diagram of an integrated circuit package with intra-package connections formed from modified ELR material. The integrated circuit package 4402 includes chips 4404 and 4406 and a conductive path 4408 of modified ELR material electrically coupling chip 4404 with 4406. Conventional conductive materials, e.g., copper and aluminum, are typically used for these inter-chip connections in integrated circuit packages. However, by using conductive paths formed of modified ELR material inter-chip communication is faster and more efficient.

[00799] Another example of modified ELR materials used in integrated circuit packaging is shown in Figure 41B. The integrated circuit package 4452 in Figure 41B includes a chip 4454, pins 4456 to connect the chip to outside components, and a modified ELR nanowire 4458 to electrically couple the pins 4456 with the chip 4454. In some examples, the pins 4456 can also be formed of modified ELR material. The advantages described above that are realized from using modified ELR materials for conductive paths can be used to more quickly and efficiently transmit signals to the system in which the packaged integrated circuit is a component.

[00800] In addition to the systems, devices, and/or applications described herein, one skilled in the art will realize that other systems, devices, materials and applications that include conductive paths may utilize the ELRIs described herein.

[00801] In the Figures, sizes of various depicted elements or components and the lateral sizes and thicknesses of various layers are not necessarily drawn to scale and these various elements may be arbitrarily enlarged or reduced to improve legibility. Also, component details have been abstracted in the Figures to exclude details such as precise geometric shape or positioning of components and certain precise connections between such components when such details are unnecessary to the detailed description of the invention. When such details are unnecessary to understanding the invention, the representative geometries, interconnections, and configurations shown are intended to be illustrative of general design or operating principles, not exhaustive.

[00802] In some implementations, an integrated circuit, component, and/or device includes modified ELR materials may be described as follows:

[00803] An integrated circuit comprising: an input/output pad; an electrostatic discharge protection circuit; a conductive path coupling the input/output pad with the electrostatic discharge protection circuit; and a ground network coupled with the electrostatic

discharge protection circuit; wherein the conductive path and the ground network are formed of a modified extremely low resistance (ELR) material having a first layer comprised of an ELR material and a second layer comprised of a modifying material bonded to the ELR material of the first layer.

[00804] An integrated circuit comprising: a dielectric substrate; a conductive path disposed on the dielectric substrate of the integrated circuit, the conductive path formed of a modified extremely low resistance (ELR) material having a first layer comprised of an ELR material and a second layer comprised of a modifying material bonded to the ELR material of the first layer; and wherein at least a portion of the conductive path is a laser modified section, such that the laser modified section has a higher resistance than the rest of the conductive path.

[00805] An integrated circuit comprising: a dielectric substrate; a conductive path disposed on the dielectric substrate of the integrated circuit, the conductive path formed of a modified extremely low resistance (ELR) material having a first layer comprised of an ELR material and a second layer comprised of a modifying material bonded to the ELR material of the first layer; and wherein a plurality of sections of the conductive path include at least one laser modified section, such that the at least one laser modified section has a higher resistance than the rest of the conductive path.

[00806] An integrated circuit comprising: a conductive path disposed on a dielectric layer of the integrated circuit, wherein the conductive path is formed of a modified extremely low resistance (ELR) material having a first layer comprised of an ELR material and a second layer comprised of a modifying material bonded to the ELR material of the first layer; and a magnetic field source to produce a magnetic field affecting a portion of the conductive path such that the modified ELR material of the affected portion of the conductive path is more resistive than a non-affected portion.

[00807] An integrated circuit comprising: a conductive path disposed on a dielectric layer of the integrated circuit, wherein the conductive path is formed of a modified extremely low resistance (ELR) material having a first layer comprised of an ELR material and a second layer comprised of a modifying material bonded to the ELR material of the first layer; and a magnetoresistive random access memory (MRAM) cell to produce a magnetic field affecting a portion of the conductive path such that the modified ELR material of the affected portion of the conductive path is more resistive than a non-affected portion.

[00808] An integrated circuit comprising: a dielectric substrate; a conductive path disposed on the dielectric substrate of the integrated circuit, the conductive path formed of a modified extremely low resistance (ELR) material having a first layer comprised of an ELR material and a second layer comprised of a modifying material bonded to the ELR material of the first layer; and wherein at least a portion of the conductive path has different dimensions than the rest of the conductive path to define a current limiting element, such that the critical current of the current limiting element is less than the critical current of the rest of the conductive path.

[00809] An integrated circuit (IC) comprising: a plurality of conductive paths, wherein at least one of the plurality of conductive paths is comprised of an extremely low resistance interconnect (ELRI) having a first layer comprised of an extremely low resistance (ELR) material and a second layer comprised of a modifying material bonded to the ELR material of the first layer; a microelectromechanical system (MEMS); and a set of circuitry connected to the MEMS through the one or more conductive paths.

[00810] An integrated circuit (IC) comprising: one or more conductive paths comprised of an extremely low resistance interconnect (ELRI) having a first layer comprised of an extremely low resistance (ELR) material and a second layer comprised of a modifying material bonded to the ELR material of the first layer; a network of one or more microelectromechanical systems (MEMS); and a set of circuitry coupled to the network of MEMS through the one or more conductive paths.

[00811] An integrated circuit (IC) comprising: one or more conductive paths comprised of an extremely low resistance interconnect (ELRI) having a first layer comprised of an extremely low resistance (ELR) material and a second layer comprised of a modifying material bonded to the ELR material of the first layer; a microelectromechanical system (MEMS); and a set of passive components connected to the MEMS through the one or more conductive paths.

[00812] An integrated circuit (IC) package comprising: an IC mounting substrate having one or more conductive paths comprised of an extremely low resistance interconnect (ELRI) having a first layer comprised of an extremely low resistance (ELR) material and a second layer comprised of a modifying material bonded to the ELR material of the first layer; a microelectromechanical system (MEMS); and a network of components connected to the MEMS through the one or more conductive paths.

[00813] A microelectromechanical system (MEMS) comprising: one or more components each including a first layer having an extremely low resistance (ELR)

material and a second layer having a modifying material bonded to the ELR material of the first layer.

[00814] A microelectromechanical system (MEMS) comprising: an input port to receive an input signal from outside the MEMS; a component configured to receive the input signal and generate a response; and one or more conductive paths connecting the component to the input port to allow the input signal to be transferred to the component, wherein the one or more conductive paths include a first layer comprised of an extremely low resistance (ELR) material and a second layer comprised of a modifying material bonded to the ELR material of the first layer.

[00815] A microelectromechanical system (MEMS) comprising: an output port; a component configured to generate a signal; and one or more conductive paths connecting the component to the output port to allow the signal generated by the component to be transferred to the output port, wherein the one or more conductive paths include a first layer comprised of an extremely low resistance (ELR) material and a second layer comprised of a modifying material bonded to the ELR material of the first layer.

[00816] An integrated circuit (IC) comprising: an IC mounting substrate; and a radio frequency (RF) component on the IC mounting substrate, wherein the RF component includes subcircuits interconnected through one or more conductive paths comprising a modified extremely low resistance interconnect (ELRI) having a first layer comprised of an extremely low resistance (ELR) material and a second layer comprised of a modifying material bonded to the ELR material of the first layer.

[00817] An integrated circuit (IC) comprising: a radio frequency (RF) antenna having one or more conductive paths, wherein the one or more conductive paths include a modified extremely low resistance interconnect (ELRI) having a first layer comprised of an extremely low resistance (ELR) material and a second layer comprised of a modifying material bonded to the ELR material of the first layer.

[00818] A monolithic microwave integrated circuit (MMIC) made from a single piece of silicon, the MMIC comprising: extremely low resistance interconnects (ELRIs) having a first layer comprised of an extremely low resistance (ELR) material and a second layer comprised of a modifying material bonded to the ELR material of the first layer a radio frequency (RF) filter including one or more passive elements; an RF amplifier connected to the RF filter by the ELRIs; and an RF antenna connected to the RF amplifier by the ELRIs.

[00819] A wireless device comprising: a monolithic microwave integrated circuit (MMIC) having a radio frequency (RF) transceiver and receiver circuit coupled to the power supply, wherein the RF transceiver and receiver circuit includes: extremely low resistance interconnects (ELRIs) having a first layer comprised of an extremely low resistance (ELR) material and a second layer comprised of a modifying material bonded to the ELR material of the first layer a radio frequency (RF) filter including one or more passive elements; an RF amplifier connected to the RF filter by the ELRIs; and a RF antenna connected to the RF amplifier by the ELRIs.

[00820] An integrated circuit (IC) comprising: an IC substrate having one or more conductive paths comprised of an extremely low resistance interconnect (ELRI) having a first layer comprised of an extremely low resistance (ELR) material and a second layer comprised of a modifying material bonded to the ELR material of the first layer; a set of circuitry implemented on the IC substrate; a first programmable block connected to the set of circuitry through the one or more conductive paths, and wherein the first programmable block includes: a digital signal processor (DSP) implemented on the substrate; a radio frequency (RF) transmitter coupled to the DSP; and an embedded core implemented on the IC substrate, wherein the embedded core is programmable to perform one or more functions and is coupled to the DSP; and a set of programmable ELRI blocks comprising components made from the ELRI.

[00821] An integrated circuit comprising: a substrate; and a plurality of conductive paths disposed on the substrate; wherein at least one of the plurality of conductive paths is formed of a modified extremely low resistance (ELR) material having an ELR material and a modifying material bonded to the ELR material.

[00822] An integrated circuit comprising: a first component; a second component; and a plurality of conductive paths including a specific conductive path electrically coupling the first component to the second component; wherein the specific conductive path is formed of a modified extremely low resistance (ELR) film having a first layer comprised of an ELR material and a second layer comprised of a modifying material bonded to the ELR material of the first layer.

[00823] A power distribution network for an integrated circuit comprising: a conductive path for electrically coupling a power supply to at least one component of the integrated circuit, the power supply either external or internal to the integrated circuit, the conductive path disposed on a substrate of the integrated circuit; wherein the conductive path is formed of a modified extremely low resistance (ELR) film having a first layer

comprised of an ELR material and a second layer comprised of a modifying material bonded to the ELR material of the first layer.

[00824] A clock distribution network for an integrated circuit comprising: a clock driver; a trunk conductive path electrically coupled with the clock driver, the conductive path formed of a modified extremely low resistance (ELR) film having a first layer comprised of an ELR material and a second layer comprised of a modifying material bonded to the ELR material of the first layer; and a plurality of branch conductive paths electrically coupled with the trunk conductive path through a plurality of vias, the plurality of branch conductive paths formed of the modified ELR film.

[00825] A signal distribution network for an integrated circuit comprising: a plurality of conductive paths disposed on a substrate of the integrated circuit; wherein at least one of the plurality of conductive paths is formed of a modified extremely low resistance (ELR) film having a first layer comprised of an ELR material and a second layer comprised of a modifying material bonded to the ELR material of the first layer.

[00826] An integrated circuit comprising: an analog circuit; and a compensation circuit electrically coupled with the analog circuit by a conductive path; wherein the conductive path is formed of a modified extremely low resistance (ELR) film having a first layer comprised of an ELR material and a second layer comprised of a modifying material bonded to the ELR material of the first layer.

[00827] An integrated circuit comprising: a plurality of memory cells; and a sense amplifier electrically coupled with a memory cell of the plurality of memory cells; wherein the plurality of memory cells are coupled with the sense amplifier through a plurality of conductive paths, wherein at least one of the plurality of conductive paths is formed of a modified extremely low resistance (ELR) film having a first layer comprised of an ELR material and a second layer comprised of a modifying material bonded to the ELR material of the first layer.

[00828] A data flow processor comprising: a function cell; a bus electrically coupled with the function cell; and an instruction line coupled with the function cell; wherein the bus and the instruction line are formed of a modified extremely low resistance (ELR) film having a first layer comprised of an ELR material and a second layer comprised of a modifying material bonded to the ELR material of the first layer.

[00829] An integrated circuit (IC) comprising: an IC mounting substrate with one or more conductive paths comprising a modified extremely low resistance interconnect (ELRI) having a first layer comprised of an extremely low resistance (ELR) material and a

second layer comprised of a modifying material bonded to the ELR material of the first layer; a radio frequency (RF) antenna implemented on the IC mounting substrate; and an RF circuit implemented on the IC mounting substrate, wherein the RF antenna is connected to the RF circuit through the ELRI.

[00830] An IC package comprising: a substrate; a power bus with one or more conductive paths for power distribution implemented on the substrate, wherein the one or more conductive paths include a first layer comprised of an extremely low resistance (ELR) material and a second layer comprised of a modifying material bonded to the ELR material of the first layer; and one or more virtual nodes formed by ground connections routed around the substrate, wherein the ground connections include a first ground connection layer comprised of a second ELR material and a second ground connection layer comprised of a second modifying material bonded to the second ELR material of the first ground connection layer.

[00831] An improved signal routing path for use on a substrate, the signal routing path including one or more conductive paths, wherein the improvement is characterized in that the one or more conductive paths each include a first layer comprised of an extremely low resistance (ELR) material and a second layer comprised of a modifying material bonded to the ELR material of the first layer.

[00832] A System-in-Package (SiP) comprising: a plurality of chips; and a conductive path electrically coupling a first chip of the plurality of chips with a second chip of the plurality of chips; wherein the conductive path is formed of a modified extremely low resistance (ELR) film having a first layer comprised of an ELR material and a second layer comprised of a modifying material bonded to the ELR material of the first layer.

Chapter 9 – Rotating Machines Formed of ELR Materials

[00833] This chapter of the description refers to Figures 1-36 and Figures 37A-J through Figure 42-J; accordingly all reference numbers included in this section refer to elements found in such figures.

[00834] Rotating machines, such as motors, generators, energy conversion devices, and/or flywheels, that include components formed of modified, apertured, and/or other new extremely low resistance (ELR) materials, are described. In some examples, the rotating machines include rotors having windings formed of ELR materials, stators having windings formed of ELR materials, and/or other components formed of ELR materials. For example, the windings of a rotor are composed of a modified ELR film having a YBCO layer and a modifying layer. The modified ELR materials provide

extremely low resistances to current at temperatures higher than temperatures normally associated with current high temperature superconductors (HTS), enhancing the operational characteristics of the rotating machines at these higher temperatures, among other benefits.

[00835] In some examples, the ELR materials are manufactured based on the type of materials, the application of the ELR materials, the size of the component employing the ELR materials, the operational requirements of a device or machine employing the ELR materials, and so on. As such, during the design and manufacturing of a rotating machine, the material used as a base layer of a modified ELR film and/or the material used as a modifying layer of the modified ELR film may be selected based on various considerations and desired operating and/or manufacturing characteristics.

[00836] Figure 37A-J is a schematic diagram illustrating a rotating machine 3700 utilizing ELR materials. The rotating machine 3700 includes a stator 3710 and a rotor 3720, or armature. The stator 3710, in this example a permanent magnet having a north "N" pole and an opposing south "S" pole, produces a magnetic field within a gap 3712 that contains an ELR-based winding 3730 of the rotor 3720. The winding 3730 is formed of modified, apertured, and/or other new ELR materials, such as a film having a ELR material base layer and a modifying layer formed on the base layer. Various suitable ELR materials are described in detail herein.

[00837] A battery 3726 or other electricity source applies a voltage (AC or DC) to the ELR-based winding 3730 via leads 3728, causing current to flow within the ELR-based winding 3730. The ELR-based winding 3730 provides little or no resistance to the flow of current in the winding 3730 at temperatures higher than those used in conventional HTS materials, such as room or ambient temperatures (e.g., at ~21 degrees C). The current flow in the ELR-based winding 3730 produces a magnetic field within the magnetic field of the stator 3710, producing torque on the rotor 3720 and causing the rotor 3720 to rotate within the gap 3712 (i.e., the winding 3730 rotates in and out of the page) or otherwise relative to the stator 3710, such as about an axle 3724 or other support structure of the rotor 3720, and/or about itself, such as for rotors that do not include a support structure.

[00838] In some examples, the ELR material that forms the winding 3730, or other components, may provide extremely low resistance to the flow of current at temperatures between the transition temperatures of conventional HTS materials (e.g., at ~80 to 135K) and room temperatures (e.g., ~294K), or other temperatures lower than a temperature

surrounding the winding 3730 or an associated rotating machine. For example, the ELR material may provide extremely low resistance to the flow of current at temperatures between 150K and 313K, or higher.

[00839] Figure 37B-J is a schematic diagram illustrating a rotating machine 3750 having a cooling system. Similar to the rotating machine 3700 shown in Figure 37A-J, the rotating machine 3750 includes a stator 3710 and a rotor 3720 having an ELR-based winding 3730 that provides extremely low resistance to the flow of current at various high temperatures (e.g. at T > 150K). The rotating machine 3750 includes a cooling system 3760, such as a cyrocooler or cryostat, used to cool the winding 3730 to a critical temperature for the type of modified ELR film utilized in the winding 3730 of the rotating machine 3750. For example, the cooling system 3760 may be a system capable of cooling the winding 3730 to a temperature similar to that of liquid Freon, to a temperature similar to that of ice, or other temperatures discussed herein. That is, the cooling system may be selected based on the type and structure of the ELR material utilized in the winding 3730 of the rotor 3720, and may cool the winding 3730 to a temperature lower than a surrounding temperature of the winding 3730.

[00840] In some examples, the cooling system 3760 may include or communicate with a monitoring component (not shown). The monitoring component may monitor, among other things, a temperature of an ELR winding, rotor, stator, and/or rotating machine, a resistivity of an ELR component, and other parameters. During monitoring, the monitoring component may cause the cooling system to increase and/or decrease an applied temperature or coolant when a monitored parameter satisfies a certain threshold. For example, if a monitored temperature rises above (or approaches) a critical temperature of an ELR material, the monitoring component may cause the cooling system to lower a temperature of the ELR material. Of course, one of ordinary skill in the art will appreciate that other techniques may be employed when monitoring and/or adjusting operation of a cooling system.

[00841] Although shown in Figures 37A-J and 37B-J in a general fashion, the rotating machines 3700 or 3750 may be a DC motor, an AC motor, a generator, an alternator, a mechanical energy to electrical energy converter, an inverter, or other machines and devices that convert electrical energy to mechanical energy and/or one form of electrical energy to another form of electrical energy (e.g., AC to DC). Further details regarding various rotating machines that may benefit from implementing ELR materials are discussed herein.

[00842] In addition to the stand alone winding shown in Figure 37A-J and 37B-J, the rotor 3720 of the rotating machine 3700 may be configured in a variety of ways, based on a number of factors, including the type of rotating machine, the use or application of the rotating machine, the size of the rotating machine, the operation requirements of the rotating machine, the type of ELR material, and so on. Figures 38A-J to 38G-J are schematic diagrams of various rotors for use within rotating machines that utilize modified, apertured, and/or other new ELR materials, although one of ordinary skill will appreciate that other rotors not specifically discussed may also utilize the ELR materials discussed herein.

[00843] Figure 38A-J is a schematic diagram illustrating a rotor 3800 having a winding formed of an ELR film 3802 and a support structure 3804 supporting the modified ELR film 3802. The ELR film 3802 may be formed on the support structure 3804, such as by forming the ELR film 3802 into a tape, foil or other similar component. The support structure 3804 may be formed of iron or other suitable materials (e.g., other magnetic materials, ceramics, amorphous metals, and so on) capable of providing support to the ELR film, providing strength to magnetic fields produced by current flowing through the ELR film 3802, and so on.

[00844] There are various techniques for producing and manufacturing tapes of ELR materials. In some examples, the technique includes depositing YBCO or another ELR material on flexible metal tapes coated with buffering metal oxides, forming a "coated conductor. During processing, texture may be introduced into the metal tape itself, such as by using a rolling-assisted, biaxially-textured substrates (RABiTS) process, or a textured ceramic buffer layer may instead be deposited, with the aid of an ion beam on an untextured alloy substrate, such as by using an ion beam assisted deposition (IBAD) process. The addition of the oxide layers prevents diffusion of the metal from the tape into the ELR materials. Other techniques may utilize chemical vapor deposition CVD processes, physical vapor deposition (PVD) processes, atomic layer-by-layer molecular beam epitaxy (ALL-MBE), and/or other solution deposition techniques to produce modified ELR tapes.

[00845] Figure 38B-J is a schematic diagram illustrating a rotor 3810 having a winding formed as an ELR-based wire 3812, and a support layer 3814. Although the wire 3812 is formed within the support layer 3814 in the Figure, in some cases the wire may stand-alone or be formed around a support layer 3814.

[00846] In forming an ELR wire, multiple ELR tapes or foils may be sandwiched together to form a macroscale wire. For example, a winding may include a supporting structure and one or more ELR tapes or foils supported by the supporting structure.

[00847] In addition to ELR wires, the windings described herein may be formed of ELR nanowires. In conventional terms, nanowires are nanostructures that have widths or diameters on the order of tens of nanometers or less and generally unstrained lengths. In some cases, the ELR materials may be formed into nanowires having a width and/or a depth of 50 nanometers. In some cases, the ELR materials may be formed into nanowires having a width and/or a depth of 40 nanometers. In some cases, the ELR materials may be formed into nanowires having a width and/or a depth of 30 nanometers. In some cases, the ELR materials may be formed into nanowires having a width and/or a depth of 20 nanometers. In some cases, the ELR materials may be formed into nanowires having a width and/or a depth of 10 nanometers. In some cases, the ELR materials may be formed into nanowires having a width and/or a depth of 5 nanometers. In some cases, the ELR materials may be formed into nanowires having a width and/or a depth less than 5 nanometers.

[00848] Figure 38C-J is a schematic diagram illustrating a rotor 3820 having a winding 3822 formed of ELR materials, such as a modified ELR tape or wire, and a core or shaft 3824, such as an iron core. In some cases, the number of turns in the winding 3822 is selected based on the desired torque on the rotor 3820, or other factors. In some cases, the type of material used for the winding 3822 and/or the core 3824 is selected based on the desired torque on the rotor 3820, or other factors.

[00849] Figure 38D-J is a schematic diagram illustrating a rotor 3830 having a winding 3832 formed of ELR materials, such as a modified ELR tape or wire, and a circular core 3834, such as an iron core. In some cases, the number of turns in the winding 3822 is selected based on the desired torque on the rotor 3830, or other factors. In some cases, the type of material used for the winding 3832 and/or the core 3834 is selected based on the desired torque on the rotor 3830, or other factors.

[00850] Figure 38E-J is a schematic diagram illustrating a rotor 3840 having rods 3842 formed of ELR materials, such as a modified ELR tape or nanowire, and a supporting structure 3844. The rotor 3840 may be similar to the squirrel cage rotors known in the art, or other similar rotors.

[00851] Figure 38F-J is a schematic diagram illustrating a rotor 3850 having a ring 3852 formed of ELR materials, and one or more supporting rings 3854. In some cases, the

ELR ring 3852 may be one continuous ring around the axis of rotation of the rotor 3850. In some cases, the ELR ring 3852 may be two or more discrete rings around the axis of rotation of the rotor 3850.

[00852] Figure 38G-J is a schematic diagram illustrating a rotor 3860 having multiple strips or rods 3862 formed of ELR materials, such as modified ELR tapes or nanowires, and a support structure 3864. In some cases the ELR strips or rods 3862 are formed on a support structure 3864 that extends the length of the rotor 3860. In some cases, the support structure 3864 supports the ends of the strips or rods 3862, and the rotor 3860 is similar in construction to a squirrel cage rotor.

[00853] As mentioned above, one of ordinary skill will appreciate that the rotors contemplated for use with the ELR materials described herein may take on forms other than those illustrated in Figures 38A-J to 38G-J. That is, the ELR materials may be manufactured in a variety of ways to achieve the desired forms. The ELR materials may formed into wires, tapes, rods, strips, nanowires, films, foils, other shapes or structures, and/or other geometries capable of moving or carrying current from one point to another in order to produce a magnetic field. While some suitable geometries are shown and described herein for some windings, rotors, stators, and/or other components, numerous other geometries are possible. These other geometries include different patterns, configurations or layouts with respect to length and/or width, in addition to differences in thickness of materials, use of different layers, and other three – dimensional structures.

[00854] In some examples, the type of ELR materials used in windings and/or other components or devices may be determined by the type of application utilizing the ELR materials. For example, some applications may utilize ELR materials having a BSCCO ELR layer, whereas other applications may employ a YBCO ELR layer. That is, the ELR materials described herein may be formed into certain structures (e.g., tapes or wires) and formed from certain materials (e.g., YBCO or BSCCO) based on the type of machine or component utilizing the ELR materials, among other factors.

[00855] In addition to rotors, other components of a rotating machine may utilize the ELR materials described herein. For example, stators having conductive windings, leads between components (such as battery leads), and other components may employ ELR materials. Various rotating machines and components that may utilize the ELR materials described herein will now be discussed.

[00856] Figures 37A-J and 37B-J depict rotating machines having a rotor with a modified ELR film winding that carries current at an extremely low resistance to produce a

magnetic field. However, in some examples, a rotating machine may include a stator having a modified ELR film winding that carries current to produce a magnetic field in a gap housing a rotor. Figure 39-J is a schematic diagram of a rotating machine 3900 having a stator with an ELR winding. The rotating machine 3900 includes a stator having a support structure 3912 and a winding 3914 formed of modified, apertured, and/or other new ELR materials, such as a modified ELR wire or tape. A rotor 3920 sits within a gap 3915 of the stator 3910. The rotor 3920 includes one or more ELR components, such as rods 3922, held together by a support structure 3924.

[00857] As discussed herein, the ELR winding 3914 and/or the ELR rods 3922 may be formed in a variety of ways using a variety of different materials. For example, the winding may be formed of a modified ELR tape or wire.

[00858] Thus, the ELR materials described herein may be utilized as or within a variety of different components of a rotating machine, including as or within the winding of a rotor, as or within the winding of a stator, as or within a rod or a rotor, as or within a tape, as or within a ring, as a lead or other connective element between components, and so on. A large variety of rotating machines, including motors, generators, alternators, rotating energy converters (AC to DC, DC to DC, DC to AC), flywheels, and others, may utilize such films. A few examples will now be discussed.

[00859] Figure 40-J is a schematic diagram of a brushed DC motor 4000 employing ELR materials. The brushed DC motor 4000 includes a stator 4010 formed of a permanent magnet, a rotor 4020 formed of a core 4022 (e.g., iron, ceramic, amorphous metal, air), and an ELR-based winding 4024, an axle 4021 or other support that facilitates rotation of the rotor 4020 within the stator 4010, brushes 4026 that provide current to the windings 4024 from a current source 4030, and a commutator 4028 that commutates the windings 4024 of the rotor 4020.

[00860] Various types of brushed DC motors, or stepper motors, may utilize modified ELR films as or within various components, including Permanent Magnet Brushed DC (PMDC) motors, Shunt-Wound Brushed DC (SHWDC) motors, Series-Wound Brushed DC (SWDC) motors, Compound Wound (CWDC) motors, and so on.

[00861] Figure 41-J is a schematic diagram of a brushless DC motor 4100 employing ELR materials. The brushless DC motor 4100 includes a stator 4110 formed of a support structure 4114 and a modified ELR film winding 4112, hall effect sensors 4116 and hall effect commutators 4118, and a rotor 4120 formed of a permanent magnet that rotates

within the stator 4110. Various types of brushless DC motors, or electronically commutating motors, may utilize ELR materials as or within various components.

[00862] Figure 42-J is a schematic diagram of an AC motor 4200 employing ELR materials. The AC induction motor 4200 includes a stator 4210 having an ELR winding 4214 wrapped around poles 4212 of the stator 4210, and a rotor 4220, having conductive elements 4222 (which may be ELR materials) and a shaft 4224 or other support structure, that rotates within the stator 4210.

[00863] Various types of AC motors may utilize ELR materials as or within various components, including Single-Phase Induction motors (e.g., Split-Phase Induction motors, Capacitor Start Induction motors, Permanent Split Capacitor Induction motors, Capacitor Start/Capacitor Run Induction motors, Shaded-Pole AC Induction motors, and so on) and Three-Phase Induction motors (e.g., Squirrel Cage motors, Wound-Rotor motors, and so on).

[00864] Of course, one of ordinary skill in the art will appreciate other rotating machines may employ the ELR materials described herein, including Universal motors, Printed Armature or Pancake motors, Servo motors, Electrostatic motors, Torque motors, Stepper motors, Hub motors, Fan motors, generators, alternators, air core motors, flywheels, magnetic clutches, power machines, and/or other rotating machines.

[00865] The various rotating machines described herein may perform with improved or enhanced operating characteristics by utilizing modified, apertured, and/or other new ELR materials. For example, the rotating machines may exhibit fewer resistive losses from the resistances of various conductive elements, such as windings, leads, capacitive elements, and so on. It follows that devices employing rotating machines having improved operating characteristics may in turn benefit with similar improvements. Examples of devices that may employ rotating machines utilizing modified ELR materials include fans, turbines, drills, pumps, electric drive trains, the wheels on electric cars, train locomotive traction, electric clutches, conveyor belts, robots, vehicles, appliances, engines, manufacturing equipment, information storage systems, e.g. hard disk drives, physical exercise equipment, prosthetic devices, exoskeletons, toys, roller skates/blades, lawn and garden equipment, shoes, furniture, and many others.

[00866] In some implementations, a rotating machine that includes modified ELR materials may be described as follows:

[00867] A rotating machine, comprising: a stator assembly; and a rotor assembly positioned to rotate within the stator assembly, wherein the rotor assembly includes a support structure and a winding formed of a modified ELR material.

[00868] A rotor for use in a rotating machine, the rotor comprising: a support structure; and a winding coupled to the support structure and formed of a modified ELR material.

[00869] A rotating machine, comprising: a stator; and a rotor, wherein the rotor is formed of a material that provides extremely low resistances to electric current at temperatures greater than 150 Kelvin at standard pressure.

[00870] A rotor assembly for use in a rotating machine, the rotor assembly comprising: a core structure formed of a magnetic material; and a modified ELR film configured to carry electric current, wherein the modified ELR film is formed of a first layer comprised of an ELR material and a second layer comprised of a modifying material bonded to the ELR material of the first layer.

[00871] A stator assembly for use in a rotating machine, the stator assembly comprising: a support structure; and a modified ELR film configured to carry electric current, wherein the modified ELR film is formed of a first layer comprised of an ELR material and a second layer comprised of a modifying material bonded to the ELR material of the first layer.

[00872] A winding configured to carry an electric current in order to produce a magnetic field within a rotating machine, the winding comprising: a first layer, wherein the first layer is comprised of an ELR material; and a second layer, wherein the second layer is comprised of a modifying material bonded to the ELR material of the first layer.

[00873] A rotating machine, comprising: a stator assembly, wherein the stator assembly includes a support structure and a winding formed of a modified ELR material; and a rotor positioned to rotate within the stator assembly.

[00874] A stator for use in a rotating machine, the stator comprising: a support structure; and a winding coupled to the support structure and formed of a modified ELR material.

[00875] A rotating machine, comprising: a rotor; and a stator, wherein the stator is formed of a material that provides extremely low resistances to electric current at temperatures greater than 150 Kelvin at standard pressure.

[00876] A rotating machine, comprising: a stator assembly; a rotor assembly positioned to rotate within the stator assembly, wherein the rotor assembly includes a support structure and a winding formed of a modified ELR material; and a cooling system that

maintains the winding formed of the modified ELR material at a temperature between 135K and 273K.

[00877] A rotating machine, comprising: a stator assembly, wherein the stator assembly includes a support structure and a winding formed of a modified ELR material; a rotor assembly positioned to rotate within the stator assembly; and a cooling system that maintains the winding formed of the modified ELR film at a temperature lower than a temperature surrounding the winding.

[00878] A rotating machine, comprising: a stator; a rotor, wherein the rotor is formed of a material that provides extremely low resistances to electric current at temperatures between 150K and 313K; and a cooling component that maintains the material providing extremely low resistances to electric current at or below a critical temperature of the material.

[00879] A DC motor, comprising: a stator assembly, wherein the stator assembly includes a gap configured to receive a rotor assembly; and a rotor assembly configured to rotate within the gap of the stator, the rotor assembly comprising: a core structure formed of a magnetic material; and a winding of modified ELR material configured to carry electric current, wherein the modified ELR material is formed of a first layer comprised of an ELR material and a second layer comprised of a modifying material bonded to the ELR material of the first layer.

[00880] An AC induction motor, comprising: a rotor assembly configured to rotate within a gap of a stator assembly, wherein the rotor assembly is formed of a magnetic material; and a stator assembly configured to provide a gap in which to receive the rotor assembly, the stator assembly comprising: a support structure; and a modified ELR material configured to carry electric current, wherein the modified ELR material is formed of a first layer comprised of an ELR material and a second layer comprised of a modifying material bonded to the ELR material of the first layer.

[00881] A brushed DC motor, comprising: a stator formed of a permanent magnet; and a rotor formed of an iron core and a modified ELR winding, wherein the modified ELR winding carries current at approximately zero resistance under ambient temperatures.

[00882] A DC motor, comprising: a stator assembly, wherein the stator assembly includes a gap configured to receive a rotor assembly; and a rotor assembly configured to rotate within the gap of the stator, the rotor assembly comprising: a winding of modified ELR material configured to carry electric current, wherein the modified ELR

material is formed of a first layer comprised of an ELR material and a second layer comprised of a modifying material bonded to the ELR material of the first layer.

[00883] An AC induction motor, comprising: a rotor assembly configured to rotate within a gap of a stator assembly, wherein the rotor assembly is formed of a magnetic material; and a stator assembly configured to provide a gap in which to receive the rotor assembly, the stator assembly comprising: a support structure; and a modified ELR material configured to carry electric current, wherein the modified ELR material is formed of a first layer comprised of an ELR material and a second layer comprised of a modifying material bonded to the ELR material of the first layer.

[00884] A brushed DC motor, comprising: a stator formed of a permanent magnet; and a rotor formed of a non-magnetic core and a modified ELR winding, wherein the modified ELR winding carries current at approximately zero resistance under ambient temperatures.

[00885] A vehicle, comprising: a DC motor, wherein the DC motor includes: a stator assembly, wherein the stator assembly includes a gap configured to receive a rotor assembly; and a rotor assembly configured to rotate within the gap of the stator, the rotor assembly comprising: a core structure formed of a magnetic material; and a winding of modified ELR material configured to carry electric current, wherein the modified ELR material is formed of a first layer comprised of an ELR material and a second layer comprised of a modifying material bonded to the ELR material of the first layer.

[00886] An electric vehicle, comprising: an induction motor, wherein the inductor motor includes: a rotor assembly configured to rotate within a gap of a stator assembly, wherein the rotor assembly is formed of a magnetic material; and a stator assembly configured to provide a gap in which to receive the rotor assembly, the stator assembly comprising: a support structure; and a modified ELR material configured to carry electric current, wherein the modified ELR material is formed of a first layer comprised of an ELR material and a second layer comprised of a modifying material bonded to the ELR material of the first layer.

[00887] A motor vehicle, comprising: a support structure; multiple rotating machines, each including at least one modified ELR component; a cooling system coupled to the multiple rotating machines and configured to maintain a temperature of the at least one modified ELR component at a temperature lower than a temperature surrounding the at least one modified ELR component; and a monitoring component coupled to the cooling system and configured to monitor a state of the at least one modified ELR component.

[00888] An appliance, comprising: a DC motor, wherein the DC motor includes: a stator assembly, wherein the stator assembly includes a gap configured to receive a rotor assembly; and a rotor assembly configured to rotate within the gap of the stator, the rotor assembly comprising: a core structure formed of a magnetic material; and a winding of modified ELR material configured to carry electric current, wherein the modified ELR material is formed of a first layer comprised of an ELR material and a second layer comprised of a modifying material bonded to the ELR material of the first layer.

[00889] An electric appliance, comprising: an induction motor, wherein the inductor motor includes: a rotor assembly configured to rotate within a gap of a stator assembly, wherein the rotor assembly is formed of a magnetic material; and a stator assembly configured to provide a gap in which to receive the rotor assembly, the stator assembly comprising: a support structure; and a modified ELR material configured to carry electric current, wherein the modified ELR material is formed of a first layer comprised of an ELR material and a second layer comprised of a modifying material bonded to the ELR material of the first layer.

[00890] A system, comprising: an ELR-based sub-assembly, including: a component formed at least in part of a modified ELR material; and a coolant interface configured to receive or discharge coolant used to maintain the modified ELR material in an ELR state.

[00891] A rotating machine, comprising: an electrical sub-assembly, wherein the electrical sub-assembly includes a modified or apertured ELR material and is configured to receive electrical energy; and a rotational sub-assembly, wherein the rotational sub-assembly is configured to provide rotational energy based on the received electrical energy.

Chapter 10 – Bearings Formed of ELR Materials

[00892] This chapter of the description refers to Figures 1-36 and Figures 37A-K through Figure 41-K; accordingly all reference numbers included in this section refer to elements found in such figures.

[00893] Bearing assemblies, such as bearings for use in rotating machines, that include components formed of modified, apertured, and/or other new extremely low resistance (ELR) materials, are described. In some examples, the bearing assemblies include bearings having windings and/or coils formed of ELR materials or other components formed of ELR materials. For example, the windings of a bearing are composed of a modified ELR film having a YBCO layer and a modifying layer. The ELR materials provide extremely low resistances to current at temperatures higher than temperatures

normally associated with current high temperature superconductors (HTS), enhancing the operational characteristics of the bearing assemblies at these higher temperatures, among other benefits.

[00894] As described herein, bearing assemblies, such as bearing assemblies that utilize levitated rotated bearings, may employ various ELR elements, such as modified ELR elements. Figure 37A-K is a block diagram of a suitable circuit 3700 including a bearing assembly employing ELR materials. The circuit 3700 includes elements that provide, control, modify, and/or maintain a current within an ELR coil or winding of a bearing assembly 3710. The circuit 3700 includes a switch 3730, a power supply 3735, a controller 3750, and an optional cooling system 3720. The power supply 3735 provides power to the bearing assembly 3710 via the switch 3730 to cause a current within the ELR coil or winding of the bearing assembly 3710. The controller 3750 controls the application of the power supply 3735 on the bearing assembly 3710.

[00895] In some examples, the ELR coil or winding within the bearing assembly 3710, or other ELR components, may provide extremely low resistance to the flow of current at temperatures between the transition temperatures of conventional HTS materials (e.g., at ~80 to 135K) and room or ambient temperatures (e.g., at ~294K), or at other temperatures lower than a temperature surrounding a coil or winding. The circuit may, therefore, include a cooling system 3720, such as a cyrocooler or cryostat, used to cool various components of the bearing assembly 3710 to a critical temperature for the type of modified ELR material utilized by the bearing assembly 3710. For example, the cooling system 3720 may be a system capable of cooling the bearing assembly 3710 to a temperature similar to that of a boiling point of liquid Freon, to a temperature similar to that of the melting point of water, or to other temperatures discussed herein. That is, the cooling system 3720 may be selected based on the type and/or structure of the modified ELR material utilized in the bearing assembly 3710, by the environment in which the bearing assembly is located, and so on.

[00896] Various systems, devices, and other apparatus may employ bearing assembly 3700 or other bearing assemblies and/or components described herein. Figure 37B-K is a block diagram of a system 3760 employing a bearing assembly, such as bearing assembly 3700. The system 3760 may include a bearing assembly 3765, such as a bearing assembly including an electromagnetic stator and rotor having ELR components. The system 3760 may also include power amplifiers 3770, which may include various ELR-based components, that amplify signals received from a signal-conditioning

component 3770, such as a proportional-integral-derivative (PID) controller, in order to control operation of the bearing assembly, among other things. Furthermore, the system 3760 may include various other circuit elements 3775 capable of receiving reference signals 3780 and sensor signals 3785 in order to provide a control feedback loop with respect to the bearing assembly 3765.

[00897] The system 3760 may be incorporated by, part of, or act as a variety of devices, such as motors and other rotating machines, toys, gyroscopes, energy storage devices, energy conversion devices, information storage devices, appliances, vehicles, and other devices and apparatus capable of utilizing a rotating bearing.

[00898] Various types and configurations of levitated bearing assemblies will now be discussed. Figure 38-K is a schematic diagram of a levitated bearing assembly 3800, such as a bearing assembly for use in a rotating machine. The bearing assembly 3800 includes an ELR bearing 3810, a magnetic rotor 3820, and a stator 3830. During operation, the bearing 3810 provides and/or generates a magnetic field that causes the rotor to levitate within a space or gap 3840 between the bearing 3810 and stator 3830.

[00899] The ELR bearing 3810 may be formed of some or all of the ELR materials described herein, such as modified and/or apertured ELR materials that exhibit extremely low resistance to current at temperatures between 150K and 313K, or higher. In some examples, the bearing 3810 may be formed of a disk of ELR material (as shown), such as a disk having a slight curvature towards center to assist in maintaining a levitated rotor 3820 over the bearing 3810. In some examples, the bearing 3810 may be a coil or winding, or other configuration of ELR elements capable of carrying a current at extremely low resistances and producing a magnetic field.

[00900] The rotor 3820 may be a permanent magnet capable of levitating and rotating between the bearing 3810 and the stator 3830. For example, the rotor 3820 may be a disk, donut, or other circular shaped objects. The rotor 3820 may be formed of multiple permanent magnets or may be formed of an electromagnet. The magnet or magnets of the rotor 3820 may be magnetized in various pole configurations in order to meet the needs of the machine utilizing the bearing assembly 3800. In some examples, the magnetization may be isotropic, anisotropic, and may have a pattern of multiple poles. For example, the rotor 3820 may include a first magnetic element coupled to the stator 3830, a second magnetic element coupled to the bearing 3810, and a buffer magnet that magnetically isolates the first magnet from the second magnet.

[00901] The stator 3830 may include an armature winding connected to a power source in order to produce a magnetic field that drives the rotor 3820. The stator may include positioning and/or sensing components, such as a Hall-effect sensing component, an electro-optical switch component, a radio frequency sensing component, and so on. The stator 3830 utilizes these components to determine information about the operation of the rotor 3820, and causes armature windings to adjust a produced magnetic field accordingly.

[00902] The bearing assembly 3800, as discussed herein, may of course utilize other bearing configurations. Figure 39A-K is a schematic diagram of a bearing 3900 that includes a substrate 3910 and a coil or winding 3920 formed of an ELR material, such as a modified and/or apertured ELR material. The bearing 3900 carries current with extremely low resistance through the coil 3820, producing a magnetic field capable of levitating a magnetic rotor, such as rotor 3820.

[00903] Figure 39B-K is a schematic diagram of a bearing 3930 that includes two or more substrates 3940 positioned together to form a modified ELR loop 3950 (or loops) capable of carrying current in order to produce a magnetic field. For example, four triangular substrates 3942 each containing a strip of ELR material 3952 are positioned adjacent to one another such that the strips of ELR material 3952 form a loop 3950 that can circulate a current with extremely low resistance and produce a magnetic field capable of levitating a magnetic rotor, such as rotor 3820.

[00904] In addition to the disk-shaped bearing assemblies shown in Figure 38-K, other bearing assemblies may utilize the ELR materials described herein. Figures 40A-K to 40C-K are schematic diagrams of various bearing assembly configurations.

[00905] In Figure 40A-K, a bearing assembly 4000 includes a rotatable shaft 4020 having a coil 4025 spaced within a gap of a bearing 4010. In some cases, the coil 4025 of the rotatable shaft 4020 is formed of ELR material, as described herein. In some cases, the bearing 4010 is formed of ELR material or includes a coil or loop formed of ELR material, as described herein. Excitation of the coil 4025 of the shaft 4020 produces a magnetic field, which causes the shaft to levitate with respect to the bearing 4010. In some cases, the bearing 4010 is formed in various shapes in order to assist in the positioning of the shaft 4020 with respect to the bearing 4010. Application of a second magnetic field by a stator and/or armature (not shown) causes the shaft to rotate while levitated.

[00906] In Figure 40B-K, a bearing assembly 4030 includes a rotatable shaft 4050 having a coil 4055 that surrounds a portion of a bearing 4040. The rotatable shaft 4050, therefore, may be donut shaped. In some cases, the coil 4055 of the rotatable shaft 4050 is formed of ELR material, as described herein. In some cases, the bearing 4040 is formed of ELR material or includes a coil or loop formed of ELR material, as described herein. Excitation of the coil 4055 of the shaft 4050 produces a magnetic field, which causes the shaft to levitate with respect to the bearing 4040. In some cases, the bearing 4040 is formed in various shapes in order to assist in the positioning of the shaft 4050 with respect to the bearing 4040. For example, the bearing 4040 includes a pedestal 4045, which may assist in centering the shaft 4050 over the bearing 4040. Application of a second magnetic field by a stator and/or armature (not shown) causes the shaft to rotate while levitated.

[00907] In Figure 40C-K, a bearing assembly 4060 includes a rotatable shaft 4080 and a bearing 4070 that includes a coil 4075 formed of an ELR material. Excitation of the coil 4075 of the bearing 4070 produces a magnetic field, which causes the shaft 4080 to levitate with respect to the bearing 4070. In some cases, the bearing 4070 may act as a stator, utilizing the coil 4075 to provide a field that levitates or positions the shaft 4080 in a space away from the bearing 4070 while also causing the shaft 4080 to rotate. In some cases, application of a second magnetic field by a stator and/or armature (not shown) causes the shaft to rotate while levitated. In some cases, the bearing 4070 is formed in various shapes in order to assist in the positioning of the shaft 4080 with respect to the bearing 4070.

[00908] Of course, one of ordinary skill in the art will appreciate that other configurations are possible. For example, the shafts described in Figures 40A-K to 40C-K may operate as bearings, and the bearings as shafts. Additionally, the bearings and/or shafts may include multiple ELR elements, such as ELR elements utilized to produce levitation of shafts with respect to bearings, ELR elements utilized to rotate shafts with respect to bearings, ELR elements utilized to control the positioning and/or rotation of shafts, and so on.

[00909] As an example, Figure 41-K illustrates a five-point shaft bearing assembly 4100. The bearing assembly 4100 includes multiple radial bearings 4110, and a rotatable shaft 4120. In some cases, the radial bearings 4110 are formed at least in part of ELR components. In some cases, the shaft is formed of ELR components, magnetic materials, or other materials. In some cases, sensors that monitor movement of the shaft and

provide feedback to a control mechanism are formed of ELR components. The bearing assembly provides 5 axis control of the shaft, such as control of rotation of the shaft, control of translation of the shaft, control of movement and/or positioning of the shaft in three-dimensional space, and so on.

[00910] As described herein, the bearings, rotors and/or stators of the various bearing assemblies may include coils, windings, and/or disks that employ ELR materials, such as modified, apertured, and/or other new ELR materials. These coils, windings, and/or disks may employ tapes, films, foils, and/or wires formed for ELR materials.

[00911] In forming an ELR wire, multiple ELR tapes or foils may be sandwiched together to form a macroscale wire. For example, a coil may include a supporting structure and one or more ELR tapes or foils supported by the supporting structure.

[00912] In addition to ELR wires, the bearings, rotors, and/or stators may be formed of ELR nanowires. In conventional terms, nanowires are nanostructures that have widths or diameters on the order of tens of nanometers or less and generally unstrained lengths. In some cases, the ELR materials may be formed into nanowires having a width and/or a depth of 50 nanometers. In some cases, the ELR materials may be formed into nanowires having a width and/or a depth of 40 nanometers. In some cases, the ELR materials may be formed into nanowires having a width and/or a depth of 30 nanometers. In some cases, the ELR materials may be formed into nanowires having a width and/or a depth of 20 nanometers. In some cases, the ELR materials may be formed into nanowires having a width and/or a depth of 10 nanometers. In some cases, the ELR materials may be formed into nanowires having a width and/or a depth of 5 nanometers. In some cases, the ELR materials may be formed into nanowires having a width and/or a depth less than 5 nanometers.

[00913] In addition to nanowires, ELR tapes or foils may also be utilized by the bearings, stators, and rotors described herein. There are various techniques for producing and manufacturing tapes and/or foils of ELR materials. In some examples, the technique includes depositing YBCO or another ELR material on flexible metal tapes coated with buffering metal oxides, forming a “coated conductor. During processing, texture may be introduced into the metal tape itself, such as by using a rolling-assisted, biaxially-textured substrates (RABiTS) process, or a textured ceramic buffer layer may instead be deposited, with the aid of an ion beam on an untextured alloy substrate, such as by using an ion beam assisted deposition (IBAD) process. The addition of the oxide layers prevents diffusion of the metal from the tape into the ELR materials. Other

techniques may utilize chemical vapor deposition CVD processes, physical vapor deposition (PVD) processes, atomic layer-by-layer molecular beam epitaxy (ALL-MBE), and other solution deposition techniques to produce ELR materials.

[00914] In some examples, the type of application utilizing the films may determine the type of materials used in the ELR materials. For example, applications may utilize ELR materials having a BSSCO ELR layer, whereas other applications may utilize ELR materials having a YBCO layer. That is, the ELR materials described herein may be formed into certain structures (e.g., tapes or wires) and formed from certain materials (e.g., YBCO or BSCCO) based on the type of bearing assembly or component utilizing the ELR materials, among other factors.

[00915] The ELR materials described herein may be utilized as or within a variety of different components of a bearing assembly utilized by a rotating machine, including as or within the winding of a bearing, as or within the winding of a rotor, as or within the winding of a stator, as or within a rod or a rotor, as or within a tape, as or within a ring, as a lead or other connective element between components, and so on. A large variety of rotating machines, including motors, generators, alternators, and others, may utilize such films.

[00916] Various types of brushed DC motors, or stepper motors, may utilize modified ELR films as or within various components, including Permanent Magnet Brushed DC (PMDC) motors, Shunt-Wound Brushed DC (SHWDC) motors, Series-Wound Brushed DC (SWDC) motors, Compound Wound (CWDC) motors, and so on.

[00917] Various types of AC motors may utilize modified ELR films as or within various components, including Single-Phase Induction motors (e.g., Split-Phase Induction motors, Capacitor Start Induction motors, Permanent Split Capacitor Induction motors, Capacitor Start/Capacitor Run Induction motors, Shaded-Pole AC Induction motors, and so on) and Three-Phase Induction motors (e.g., Squirrel Cage motors, Wound-Rotor motors, and so on).

[00918] Of course, one of ordinary skill in the art will appreciate other rotating machines may employ the modified ELR films described herein, including Universal motors, Printed Armature or Pancake motors, Servo motors, Electrostatic motors, Torque motors, Stepper motors, generators, alternators, and other rotating machines.

[00919] The various bearing assemblies described herein may perform with improved or enhanced operating characteristics by utilizing modified ELR films. For example, the bearing assemblies may exhibit fewer resistive losses from the resistances of various

conductive elements, such as windings, leads, capacitive elements, and so on, or may last longer because certain elements do not exhibit wear due to friction. It follows that devices employing bearing assemblies having improved operating characteristics may in turn benefit with similar improvements. Examples of devices that may employ bearing assemblies utilizing modified ELR films include fans, turbines, drills, the wheels on electric cars, locomotives, conveyor belts, robots, vehicles, appliances, engines, manufacturing equipment, toys, gyros, MEMS based motors and components, and many other devices employing rotating machines.

[00920] In some implementations, a bearing assembly that includes modified ELR materials may be described as follows:

[00921] A bearing assembly, comprising: a bearing formed at least in part of a modified ELR material; and a rotor formed of a magnetic material and positioned proximate to the bearing; wherein the rotor levitates relative to the bearing when a magnetic field is produced by current flowing within the modified ELR material of the bearing.

[00922] A method of manufacturing a bearing assembly, the method comprising: forming a bearing of a modified ELR material; and positioning a rotor proximate to the formed bearing, such that the rotor is capable of levitating with respect to the bearing in response to a magnetic field produced by a current traveling through the modified ELR material of the bearing.

[00923] A bearing assembly, comprising: a bearing formed of an ELR material that exhibits extremely low resistance to carried charge at temperatures above 150K.

[00924] A bearing for use within a bearing assembly, comprising: a substrate; and a coil formed at least in part of a modified ELR material.

[00925] A method of manufacturing a bearing, the method comprising: positioning a substrate; and depositing modified ELR material into a loop shape onto the positioned substrate.

[00926] A bearing for use in a levitated bearing assembly, comprising: a substrate; and a coil formed of an ELR material that exhibits extremely low resistance to carried charge at temperatures above 150K.

[00927] A bearing assembly, comprising: a bearing formed at least in part of a modified ELR material; a cooling system configured to maintain a temperature of the bearing between 150K and 313K; and a rotor formed of a magnetic material and positioned proximate to the bearing; wherein the rotor levitates above the bearing when a magnetic field is produced by current flowing within the modified ELR material of the bearing.

[00928] A method of manufacturing a bearing assembly, the method comprising forming a bearing of a modified ELR material; coupling the formed bearing to a cooling system configure to maintain a temperature of the bearing between 150K and 313K; and positioning a rotor proximate to the formed bearing, such that the rotor is capable of levitating with respect to the bearing in response to a magnetic field produced by a current traveling through the modified ELR material of the bearing.

[00929] A bearing assembly, comprising: a bearing formed of an ELR material that exhibits extremely low resistance to carried charge at temperatures between 150K and 313K; and a cooling component that maintains a temperature of the ELR material of the bearing between 150K and 313K.

[00930] A rotating machine, comprising: a bearing formed at least in part of a modified ELR material; and a rotatable shaft formed of a magnetic material and positioned proximate to the bearing; wherein the rotatable shaft is spaced a certain distance from the bearing when a magnetic field is produced by current flowing within the modified ELR material of the bearing.

[00931] A motor, comprising: a bearing assembly, wherein the bearing assembly is formed of an ELR material that exhibits extremely low resistance to carried charge at temperatures between 150K and 313K; and a power component, wherein the power component is configured to provide power to the bearing assembly to produce a current within the ELR material of the bearing assembly.

[00932] A rotating machine, comprising: a bearing configured to produce a magnetic field; and a rotor configured to rotate and positioned proximate to the bearing based on a strength of the magnetic field; wherein the bearing or the rotor includes a material that exhibits extremely low resistance to charge at ambient temperature and standard pressure.

Chapter 11 – Sensors Formed of ELR Materials

[00933] This chapter of the description refers to Figures 1-36 and Figures 37-L through Figure 88-L; accordingly all reference numbers included in this section refer to elements found in such figures.

[00934] Sensors that include components formed of modified, apertured, and/or other new extremely low resistance (ELR) materials are described. In some examples, the sensors include components that utilize nanowires of ELR materials. In some examples, the sensors include components that utilize a tape or foil formed of ELR materials. In some examples, the sensors include components that are formed using thin-film ELR

materials. The ELR materials provide extremely low resistances to current at temperatures higher than temperatures normally associated with current high temperature superconductors (HTS), enhancing the operational characteristics of the sensors at these higher temperatures, among other benefits.

[00935] Uses of modified, apertured, and/or other new ELR materials in sensors will now be described in detail. In general, various configurations of sensors that employ ELR materials are possible and depend upon a type of sensor being designed. Various principles that govern design of conventional sensors may be applied to sensors employing the ELR materials described herein. Thus, while some sensor geometries and configurations are shown and described herein, many others are of course possible. Moreover, although various examples described herein may highlight how a particular sensor system may use a sensor or sensor component formed from such ELR materials, these examples are intended to be illustrative and not exhaustive. One having ordinary skill in the art who is provided with the various examples in this disclosure would be able to identify other components within the same or a similar sensor system that might be formed from such ELR materials.

[00936] Figure 37-L is a block diagram illustrating a sensor 3700 having components formed from, or at least partially incorporating, modified, apertured, and/or other new ELR materials. Generally speaking, the sensor receives a stimulus (or measurand) s_1 and responds with an electrical output signal s_{out} that indicates a quantity, property, or condition of the stimulus. Non-exhaustive examples of stimulus and their related quantities, properties or conditions are illustrated in Table A below.

Table A: Non-exhaustive examples of stimulus.

Electric	Charge, current Potential, voltage Electric field (amplitude, phase, polarization, spectrum) Conductivity Permittivity
Magnetic	Magnetic field (amplitude, phase, polarization, spectrum) Magnetic flux Permeability
Acoustic	Wave amplitude, phase, polarization Spectrum Wave velocity
Biological	Biomass (types, concentration, states)
Chemical	Components (identities, concentration, states)

Optical	Wave amplitude, phase, polarization, spectrum Wave velocity Refractive index Emissivity, reflectivity, absorption
Mechanical	Position (linear, angular) Acceleration Force Stress, pressure Strain Mass, density Moment, torque Speed of flow, rate of mass transport Shape, roughness, orientation Stiffness, compliance Viscosity Crystallinity, structural integrity
Radiation	Type Energy Intensity
Thermal	Temperature Flux Specific heat Thermal conductivity

[00937] The sensor 3700 comprises one or more optional transducers 3705, a direct sensor 3710, and a post-processing module 3715. Each optional transducer converts a first signal having a first type of energy into a second signal having a second type of energy. For example, a first transducer 3705a may convert a mechanical stimulus signal s_1 into an optical signal s_2, which is then provided to a second transducer 3705b that converts the optical signal s_2 into a thermal signal s_3, and so on to produce an intermediary signal s_{N+1}. The direct sensor 3710 is also a transducer, but one that specifically transduces or converts an input signal into an electrical signal. The direct sensor 3710 receives the intermediary signal s_{N+1} from the one or more transducers 3705 and converts it into an electrical signal s_e. In some sensors, the transducers 3705 are omitted and the direct sensor 3710 directly receives the stimulus signal or measurand s_1. The electrical signal produced, s_e, may be modified (e.g., digitized, amplified, etc.) by the post-processing module 3715 in order to produce one or more output signals s_{out} that indicate a quantity, property, or condition of the stimulus. The post-processing module 3715 may comprise, *inter alia*, input or output terminals, conductive paths, various analog and digital post-processing electronics such as data

processors, digital signal processors, application-specific integrated circuits, amplifiers, filters, analog-to-digital converters, capacitance-to-voltage converters, differential circuits, bridge circuits, etc.

[00938] Table B shows non-exhaustive examples of the types of conversions that may be performed by the transducers 3705 and/or direct sensor 3710.

Table B: Non-exhaustive examples of types of energy conversions.

Thermoelectric
Electroelastic
Thermooptic
Photoelastic
Photomagnetic
Spectroscopy
Physical transformation
Chemical transformation
Electrochemical process
Photoelectric
Thermomagnetic
Magnetoelectric
Electromagnetic
Thermoelastic
Biochemical transformation

[00939] In some examples, the sensor 3700 may produce a non-electrical output signal s_{out} that is interpretable by a human or equipment as indicating a quantity, property, or condition of the stimulus. For example, the sensor may produce an optical output signal indicating motion. In such examples, the post-processing module 3715 may perform post-processing on an intermediary electrical signal s_e from the direct sensor 3710 in order to produce the non-electrical output signal. In some examples, the direct sensor 3710 and/or post-processing module 3715 may be omitted in such examples (e.g., if transducer 3705 produces an optical signal that is interpretable by a human).

[00940] The sensor 3700 may include other components that are not shown in Figure 37-L, including interface electronic circuits. For example, if the sensor 3700 is an active sensor, the sensor may include excitation circuits or other excitation sources (e.g., optical excitation sources). As another example, signal pre- or post-processing circuits may perform processing on a signal before or after the signal is transduced by any one of the transducers 3705 and the direct sensor 3710. Examples of other components that may be included in the sensor 3700 include processors, digital signal processors and application-specific integrated circuits, amplifiers, filters, light-to-voltage converters, excitation circuits (e.g., current generators, magnetic field sources (e.g., inductive coils or windings, including toroids, solenoids, etc.), voltage references, drivers, and optical drivers), analog-to-digital converters, waveguides, oscillators, capacitance-to-voltage

converters, ratiometric circuits, differential circuits, bridge circuits, data transmission components, ground planes/loops, antennas, bypass capacitors, components that shield against sources of noise (e.g., electrical, magnetic, mechanical, and Seebeck noise), and power sources such as batteries.

[00941] Generally speaking, sensor 3700 may include various ELR components formed in whole or in part from modified, apertured, and/or other new ELR materials. The ELR components may be configured to, e.g., conduct electrical currents, transduce or convert a signal into or out of an electromagnetic signal (including, e.g., electrical currents and voltages), or otherwise transmit or modify electromagnetic signals. For example, one or more transducers 3705, the direct sensor 3710, the post-processing module 3715, or other pre- or post-processing electronics may further comprise ELR components formed from ELR nanowires, ELR tapes, or ELR foils formed from ELR films and/or ELR thin-films. The following list provides non-exhaustive examples of components within a sensor 3700 that may employ ELR materials.

- Conductors (e.g., electrodes, contacts, wires, conductive traces/interconnections on an integrated circuit, etc.),
- Inductors, including inter alia, inductive coils or windings that may be formed as solenoids, toroids, other three dimensional shapes, printed on circuit boards and/or used as magnetic field sources,
- Capacitive elements (e.g., parallel plate capacitors, cylindrical capacitors, planar capacitors, etc.),
- Antennas.

[00942] Various sensors and/or sensor configurations may employ ELR components that are formed from ELR materials, such as those ELR components listed above, e.g., to conduct electrical currents, to transduce or convert a signal into or out of an electromagnetic signal (including, e.g., electrical currents and voltages), or otherwise transmit or modify electromagnetic signals. One having ordinary skill in the art who is provided with the various examples of ELR materials, sensing systems, and sensing principles in this disclosure would be able to implement, without undue experimentation, other sensors with one or more ELR components.

[00943] Moreover, although examples described herein may highlight how a particular sensing system may use a particular ELR component, these examples are intended to be illustrative and not exhaustive. One having ordinary skill in the art who is provided

with the various examples in this disclosure would be able to identify other components within the same or a similar sensor system that might be formed from ELR components.

[00944] Moreover, one having ordinary skill in the art will appreciate that the inventors contemplate that ELR materials may be used in complex sensing systems that comprise a combination of two or more of the discrete sensing systems and principles described herein, even if those combinations are not explicitly described.

[00945] Additionally, although this application provides examples of circuits, sensors, and other components that may be used to perform a particular measurement or characterization of a value (e.g., the measurement of a resistance, capacitance, inductance, voltage, current, impedance, electromagnetic field strength, etc.), such examples are intended to be illustrative, not exhaustive. The various alternatives for making such measurements or characterizations such as these should be readily apparent to one having ordinary skill in the art. Moreover, although various sensors may be described as "detecting," "determining," or "calculating" a particular unknown quantity (e.g., an unknown resistance), unless explicitly stated otherwise, this is not intended to denote that the sensor must directly calculate the quantity mentioned. Instead, one having skill in the art will appreciate that the quantity may be determined by the sensor indirectly or inferentially. To illustrate, if the sensor is described as "detecting a resistance of element A," this may include determining the time constant of an RLC circuit that includes the element A, since the time constant may be directly affected by the unknown resistance value.

[00946] Moreover, although various components, such as capacitive elements or plates, may be described herein as being "metallic," "conductive" or "a conductor," one having skill in the art will appreciate that in some examples, capacitive elements or plates may be formed instead from semiconductive materials, without departing from the scope of the invention.

[00947] In the Figures, sizes of various depicted elements or components and the lateral sizes and thicknesses of various layers are not necessarily drawn to scale and these various elements may be arbitrarily enlarged or reduced to improve legibility. Also, component details have been abstracted in the Figures to exclude details such as precise geometric shape or positioning of components and certain precise connections between such components when such details are unnecessary to the detailed description of the invention. When such details are unnecessary to understanding the

invention, the representative geometries, interconnections, and configurations shown are intended to be illustrative of general design or operating principles, not exhaustive.

[00948] Some or all of the systems and devices described herein may employ low cost cooling systems in applications where the specific ELR materials utilized by the application exhibit extremely low resistances at temperatures lower than ambient temperatures. As discussed herein, the application may include a cooling system (not shown), such as a system that cools ELR inductor to a temperature similar to that of the boiling point of liquid Freon, to a temperature similar to that of the melting point of water, or other temperatures discussed herein. The cooling system may be selected based on the type and structure of the ELR materials utilized by the application.

[00949] Numerous benefits may result from using ELR materials in sensing systems. For example, using ELR materials instead of HTS materials in a sensor may eliminate or reduce the complexity of cooling systems that are needed to operate the sensor, which may reduce its size, weight, and implementation and operating costs. Also, ELR materials may exhibit stronger and more nuanced temperature and photon sensitivity at higher (non-cryogenic) temperatures than HTS materials, which may provide improved thermoelectric, photoelectric, and other transduction characteristics at higher temperatures. Moreover, ELR materials may demonstrate stronger sensitivity to electromagnetic input signals and/or detect lower currents and/or lower voltages. Additionally, ELR materials may carry an electromagnetic signal (such as an input, intermediate, or output current or voltage) a much further distance than conventional conductors with less resistive loss, which may result in lower noise or less need for amplification of those signals, and/or permit lower current levels or greater separation between sensing components. Generally speaking, replacing conventional conducting and circuit elements such as copper conductors and conventional capacitors and inductors with ELR materials may reduce resistive losses, which may improve a sensor's operating efficiency, decrease waste heat, and/or improve other characteristics of its operation, such as stability, accuracy, speed of response, operating life, capital or operating costs, size, weight, feature size, sensor density, sensitivity, selectivity, hysteresis, linearity, saturation, repeatability, resolution, output impedance, and reliability. For example, using ELR materials in various components of a sensor (e.g., filters, oscillators, resonators, inductors, capacitors, amplifiers, etc.) may permit those components to operate more ideally (e.g., with a higher Q factor, greater gain, lower

noise, etc.). A more idealized performance achieved by those components may in turn improve the overall performance of the sensor.

[00950] Before explaining the details of various sensor systems, a few applications to put the sensor system 3700 in context will be described. Figure 87-L shows an example of an apparatus or system 8700 that employs the sensor system 3700. The system 8700 receives or transmits signals via one or more ports, interfaces and/or I/O components 8715 such as antennas, hard-wire data interfaces (e.g., high-speed serial buses, contact pins) and user interface components (e.g., displays, speakers, keypads, etc.). The system includes the sensor system 3700, in addition to logic and control circuitry 8705, and/or analog or RF circuitry, memory 8710, as well as also a power supply 8720, all of which may be contained within a housing, package, or otherwise aggregated as a unit. In other examples, one or more systems 8700, such as a distributed sensor system, may be controlled in whole or in part by one or more logic and control components 8705 that are remote from the systems 8700.

[00951] The system 8700 can take one of many forms. In one example, the system is a mobile phone, smart phone, laptop, tablet or other portable electronic device. Under this example, the power supply 8720 may be a battery, and the sensor system 3700 may comprise, inter alia, a microphone (e.g., to detect speech and other sounds), an accelerometer (e.g., to detect movement, acceleration, or orientation of the device), tactile input sensors (e.g., a touch screen sensor and input buttons), a light and/or imaging sensor (e.g., to obtain photographs or videos), any and all of which may be formed on one or more semiconductor chips. The logic and control circuitry 8705 can include a processor, while the interface and I/O component 8715 can include an antenna, a USB port, a keyboard or keypad, pointing device, display device, speaker, or other known elements. Many other known components in this example of a portable electronic device are of course possible, but are not shown since they will be readily understood to one of ordinary skill in the art.

I. POSITION, DISPLACEMENT, AND LEVEL SENSORS

[00952] In some examples, the sensor 3700 may be configured to provide an output signal that is indicative of the position or displacement of a physical object or the level of a fluid that is proximate to the sensor. Indicating "position" means indicating the angular or linear coordinates of an object with respect to a particular reference while indicating a "displacement" means indicating a movement of an object from a reference position.

I.A. Resistance-Based Level Sensors

[00953] Figure 38A-L shows a schematic diagram of one example of a sensor 3800 configured to produce an output signal indicative of the level of a cryogenic (e.g., liquid nitrogen, liquid helium, etc.,) or low-temperature (e.g., liquid Freon, etc.) fluid 3830 that is stored in a cryostat (or other appropriate container) 3825 with a depth D. The sensor 3800 comprises a length of an ELR material 3805 that may be disposed on or in a supporting structure 3810 that retains the length of the ELR material substantially in parallel with a major axis of the cryostat. The ELR material may be formed as an ELR nanowire, an ELR tape, an ELR thin film, and ELR foil, or other configuration. A portion of the length of ELR material may be submerged so that it is in direct or close proximity to the low-temperature fluid 3830. The sensor 3800 may comprise one or more current or voltage sources 3815 configured to deliver a known electrical current or voltage input signal to the length of ELR material. The sensor 3800 may further comprise a heater 3840 configured to dissipate heat into the ELR material in order to raise the temperature of the exposed portion of the ELR material above the temperature of the low-temperature fluid 3830. The sensor 3800 may also comprise one or more current, voltage, or impedance meters 3820 that may be coupled to the length of ELR material at one or more known positions along the length of ELR material (e.g., by switch or other coupling device).

[00954] As described above, the resistivity of ELR materials may be highly dependent upon temperature. Therefore, the composition of the length of ELR material may be selected so that it demonstrates a first, lower resistivity (R1) when it is submerged in the low-temperature fluid 3830 (e.g., submerged below the level D shown in Figure 38A-L) and demonstrates a second, higher resistivity (R2) when it is not submerged in the low-temperature fluid (and in some examples, when warmed by the heater 3840). Thus, the total resistance of the length of the ELR material will have an inverse relationship to the level D of the low-temperature liquid in the cryostat. The inverse relationship between level and resistance may be determined theoretically or experimentally (e.g., by a calibration procedure). Additionally, a measured resistivity at any given point along the length of the ELR material provides an indication of whether that point is above or below the level D of the low-temperature fluid.

[00955] The level of the low-temperature liquid 3830 may therefore be determined by the following method, which may be implemented in whole or in part by computer-readable instructions. An input current or voltage signal may be applied to the length of ELR material; also, heat may be applied to the length of ELR material to raise the temperature

of its exposed portion. The resistance of a portion of the length of ELR material may be determined, e.g., directly by using an impedance meter or indirectly by measuring a resultant voltage or current using a voltage or current meter. Using the measured resistance and a determined inverse relationship between fluid level and resistance, the level D of the low-temperature fluid may be determined. In some examples, the approximate resistivity in response to the input signal may be measured at one or more known points along the length of ELR material, and the measured resistivity may be utilized to determine which portions of the ELR material are submerged and therefore to determine the current level D of the low-temperature fluid.

[00956] The sensing principles and methods described above may be utilized in conjunction with other configurations of ELR materials that are disposed directly in or in close proximity to a liquid having a known temperature. For example, although a single length of ELR material 3805 is shown in Figure 38A-L, multiple lengths of ELR material oriented along the major axis of the cryostat may be continuously joined by additional ELR material or conductive material in order to form a longer serpentine or meandering length 3850 on or in a supporting structure, as shown in Figure 38B-L.

I.B. Potentiometric Position and Level Sensors

[00957] Figure 39A-L shows a schematic diagram of an example of a potentiometric sensor 3900 having components formed from ELR materials and configured to produce an output signal Vout indicative of the displacement ("d") or position of an object. The sensor 3900 comprises a variable voltage divider or potentiometer 3905, such as a linear or rotary potentiometer, that comprises ELR nanowires, ELR tapes, ELR thin films, ELR foils, or other formations of the ELR materials described above. For example, a wiper and/or resistive element of the potentiometer may be formed from an ELR material. An object whose position is being measured (not shown) is mechanically coupled to the wiper 3910. The position of the object may be determined by applying an input voltage source 3915 (Vin) across the two ends of the potentiometer 3905 and measuring the output voltage (Vout) at the wiper 3910. In the case of a linear potentiometer, the measured wiper voltage may be known to be approximately proportional to the displacement of the object. For other types of potentiometers, the measured wiper voltage may have another known relationship to the input voltage (e.g., a logarithmic or exponential relationship).

[00958] Figure 39B-L shows a schematic diagram of an example of a potentiometric sensor 3950 having ELR components formed from ELR materials and configured to

produce an output signal indicative of the level or depth D of a fluid 3975 in a container 3980. The elements shown in Figure 39B-L are similar to those shown in Figure 39A-L. By coupling a float 3965 to the wiper 3910 of a potentiometer 3905 formed at least in part from ELR material, the level D of the fluid may be detected using principles and methods similar to those described above.

[00959] Figure 40-L shows a cross-section of an example of another potentiometric sensor 4000 having ELR components formed from ELR materials and configured to produce an output signal (Vout) indicative of the position of an object. The sensor 4000 comprises a first flexible or depressible sheet 4005 having a conductive surface 4020 that acts as a contact strip and a second rigid surface 4015 coated with a resistive material 4010. The conductive surface 4020 and/or resistive material 4010 may be formed from ELR nanowires, ELR tapes, ELR thin films, ELR foils, or other formations of ELR material. The two sheets are physically separated by separators 4040. One of the sheets may be grounded (or otherwise held at a known voltage) and the other sheet placed in series with a known input impedance Rin and a voltage source 4025 Vin. When an object 4030, such as a finger, presses the flexible sheet at a distance d from the end of the sensor, the conductive surface 4020 contacts the resistive material 4010, and the output voltage Vout across the two sheets changes in a known manner, e.g., in a manner that is approximately proportional to the distance d of the object from the end of the sensor. Therefore, by measuring the output voltage across the two sheets (Vout), the position of the object 4030 may be determined. Such potentiometric position sensors may be used in numerous applications, including for example, audio control devices and controls on other types of consumer and commercial electronics. Many other applications are of course possible.

[00960] Although Figures 38-L to 40-L show several examples of potentiometric sensors, the examples shown are not intended to be exhaustive and are provided for illustrative purposes. Other potentiometric sensors may be designed to comprise ELR components as would be appreciated. For example, any potentiometric sensor that measures position or another stimulus by using a changing resistance may comprise resistive, conductive or other ELR components formed from ELR materials. For example, references to a wiper and potentiometer are only examples for such sensors: a sensor employing the ELR materials may employ any variable voltage divider, variable impedance element, or other structure to provide a known variable electrical output based on a given input displacement or position.

I.C. Capacitive Displacement Sensors

[00961] In some examples, the sensor 3700 includes a capacitive displacement sensor that comprises a capacitive plate or structure formed at least in part from ELR nanowires, ELR tapes, ELR thin films, ELR foils, or other formations of ELR materials. As non-exhaustive examples, a capacitive displacement sensor having one or more capacitive plates or structures formed from ELR material may be (1) a monopolar sensor that uses a single capacitor formed from two capacitive plates or structures (as shown in Figures 42-L, 44-L, and 45-L), (2) a differential sensor that uses two capacitors formed from three or more capacitive plates or structures (as shown in Figure 41-L), or (3) a capacitive bridge sensor that uses multiple capacitive plates or structures arranged in a bridge configuration (as shown in Figure 43-L).

[00962] Figure 41-L illustrates the general operating principles of capacitive displacement sensors. As shown, a capacitive displacement sensor 4100 employs a moveable capacitive plate or structure 4110 that may be displaced relative to fixed capacitive plates or structures 4105a and 4105b by a distance Δ. As a result of the changed plate geometry, capacitances C1 and C2 that exist between the moveable plate 4110 and the fixed capacitive plates 4105a and 4105b change by a known quantity that can be determined theoretically and/or experimentally. The changed capacitances alter the output voltage (Vout) that is observed in response to an input source 4150. In this way, by monitoring the output voltage (Vout), the displacement (Δ) of an object that is mechanically coupled to the moving capacitive plate or structure 4110 may be determined.

[00963] The sensors shown in Figures 42-L, 43-L and 45-L operate on similar principles. For example, a two-plate monopole sensor 4200 shown in Figure 42A-L has a fixed reference plate 4205 separated from a moveable sensing plate 4210 by a dielectric (e.g., air); the distance d between the two plates depends on the movement of the moveable sensing plate. The capacitance C1 between the two plates varies with the distance d. As shown in Figures 42B-L and 42C-L, the two-plate monopole sensor may be implemented using MEMS technology. For example, the moveable sensing plate 4210 may be micromachined so that it is supported by a flexible suspension 4220 that permits it to move in relation to a micromachined reference plate 4205 having a rigid suspension 4225. In the capacitive sensor 4300 shown in Figure 43-L, two moveable plates 4310a and 4310b are able to move in relation to four stationary plates 4305a-d arranged in a bridge configuration. In the capacitive sensor 4500 shown in the

cross-sectional view of Figure 45-L, the center conductor 4510 of a cylindrical capacitor may be a moveable capacitive element. The depth (d) to which it is inserted into a fixed outer capacitive structure 4505 affects the capacitance between the conductor 4510 and the outer structure 4505. Although a cylindrical capacitor is described, laterally moveable capacitive plates might be used in other examples. Of course, the various capacitive displacement sensors shown may also utilize additional interface electronics (e.g., inverter 4155 and amplifier/synchronous detector 4355) in order to produce a useable electronic signal indicative of the displacement or changed capacitances.

[00964] Figure 44-L shows a schematic of an example of a capacitive position sensor 4400 having components formed from ELR materials and configured to produce an output signal that is indicative of the position of a conductive object. As shown in Figure 44-L, when an object 4410 whose distance or displacement is being measured is also conductive, the capacitive sensor 4400 may be a capacitive probe having a single capacitive plate or element 4405 formed at least in part from ELR nanowires, ELR tapes, ELR thin films, ELR foils, or other formations of ELR material and configured to capacitively couple to the conductive object 4410. The capacitive plate or element 4405 may be coupled to the central conductor of a cable 4355 and/or other electronics configured to measure a capacitance between the capacitive plate or element 4405 and the conductive object 4410. The coupling capacitance may depend on the distance (a) between the capacitive plate or element 4405 and conductive object 4410. Therefore, the sensor 4400 produces an output voltage that is related in a known fashion to the distance between the probe and the object. In some examples, the sensor 4400 may also be used to detect non-conductive objects.

[00965] The example configurations of capacitive displacement sensors shown in Figures 41-L to 45-L are not intended to be exhaustive, and various configurations of capacitive plates or elements that demonstrates a changed electrical output in response to a displacement of one or more capacitive plates or elements may be used. For example, plates or elements that were previously described as moveable may be fixed and vice versa. As another example, other capacitive elements having geometries other than plates and cylinders may be used. As yet another example, capacitive displacement sensors may include shielding elements and/or guard rings, and may include one or more separating dielectrics, such as liquid, elastomeric, or other deformable/non-rigid dielectrics. In any of the configurations, one or more of the capacitive plates or elements (or other elements of the sensor) may be wholly or partially formed from ELR material.

[00966] Capacitive displacement sensors that include components formed from ELR materials may be used in many applications, including precision positioning (e.g., in semiconductor processing and testing), disk drives, machine tool metrology, assembly line testing, precise thickness measurements, and complex sensing systems where a force, pressure, or temperature causes a displacement, and other applications as would be appreciated.

I.D. Inductance Sensors, Including Variable Inductance Displacement Sensors

[00967] In some examples, the sensor 3700 comprises a variable inductance displacement sensor that comprises one or more coils (or other inductive components) formed at least in part from ELR material (e.g., ELR coils). Figure 46A-L shows a circuit schematic of an example of a linear variable differential transformer sensor 4600 having ELR components formed from ELR materials and configured to produce an output signal indicative of the position of an object. Figure 46B-L shows a cutaway view of the sensor 4600, with corresponding, simplified circuit notations. The linear variable differential transformer sensor 4600 includes a primary coil 4605, two secondary coils 4610, 4615 connected in opposed phase and positioned on either side of the primary coil, and a ferromagnetic core 4620 inserted between the primary and secondary coils (e.g., inserted coaxially into a cylindrical opening between the coils and guided along a coaxial pole 4630). Although not shown, the coils may be disposed in a supporting material that prevents them from directly contacting the core. One or more of the primary and/or secondary coils may be formed from ELR nanowires, ELR tapes, ELR thin films, ELR foils, or other formations of ELR material. The primary coil 4605 is driven by a reference voltage signal (Vref) and the differential output voltage (Vout) across the two secondary coils is measured. A displacement of the ferromagnetic core 4620 from its center position equidistant to the two secondary coils changes the path reluctance and thus the coupling between the primary and secondary coils. Therefore, the output voltage (Vout) may be monitored to determine the displacement of the ferromagnetic core and thus the displacement of an object that is mechanically coupled to the ferromagnetic core.

[00968] In other examples (not shown), the sensor 3700 may instead comprise a rotary variable differential transformer that includes a rotary ferromagnetic core and one or more coils composed of ELR materials. Such a sensor may operate on similar principles as the linear variable differential transformer sensor 4600 in order to measure angular displacement.

[00969] In still other examples of inductive sensors (not shown), one or more coils are mechanically coupled to an object whose position is being measured. In such examples, the mechanical displacement of the object results in the one or more coils being displaced relative to the other coils, which changes the level of coupling between the coils. Therefore the displacement of the object may be determined by measuring the output voltage across one or more secondary coils. In some examples, one or more coils are provided, and an object or core is moved to generate a measurable output from the coils.

[00970] Of course these examples are not intended to be exhaustive and various configurations of variable inductance or other inductance sensors may also utilize ELR material within a coil or other component as would be appreciated.

[00971] Variable inductance displacement sensors that include ELR components formed from ELR materials may be used in many applications, including position feedback in servomechanisms, gauge heads, and automated measurement in machine tools, and other applications as would be appreciated.

I.E. Eddy Current Position Sensors

[00972] Figure 47-L shows a cross-sectional schematic of an example of an eddy current sensor 4700 having components formed from ELR materials and configured to produce an output signal indicative of the position of an object. The sensor 4700 comprises a reference coil 4710 and a sensing coil 4715, both wound around a ferrite core 4720. One or more of the coils may be formed from ELR nanowires, ELR tapes, ELR thin films, ELR foils, or other formations of ELR material. Although not shown, the sensor 4700 may also include a metal guard or other guard that directs the electromagnetic field towards the front of the sensor. The eddy current sensor 4700 can be used to measure the distance d between the sensor and a conductive object 4705. The sensor 4700 induces eddy currents in the conductive object, which produces a magnetic field opposing the sensing coil, and thus changes its magnetic impedance. The changed magnetic impedance, which depends on the distance d, may be measured, e.g., by detecting a misbalance between the sensing coil and the reference coil. In some examples, the reference coil may be omitted and the changed magnetic impedance may be determined, e.g. by measuring the absolute magnetic impedance of the sensing coil or by determining the change in current needed to maintain a constant magnetic field.

[00973] Although Figure 47-L shows one example of a two-coil configuration of an eddy current sensor, the example shown is for illustrative purposes only; various suitable

configurations of a core (including ferromagnetic, ferrimagnetic, and non-ferrite cores such as air or dielectric cores) and coils/windings (including solenoids, toroids, and other arrangements) that may be used as an eddy current sensor may comprise coils or windings formed from ELR material. Also, various eddy current sensors may also use ELR coils, regardless of the mode of operation or measurement used. For example, a single coil eddy sensor design that detects an object by determining the current needed to maintain a constant magnetic field may also include a coil formed from ELR material.

[00974] Eddy current sensors having ELR materials may be used for various applications, including as a position sensor and also to sense or measure nonconductive coating thickness, material thickness, conductivity, plating, cracks, and surface flaws, and other applications, as would be appreciated.

I.F. Transverse Inductive Position Sensors

[00975] Figure 48-L shows a schematic of an example of a transverse inductive proximity sensor 4800 having components formed from ELR materials and configured to produce an output signal indicative of the position of a ferromagnetic object 4805. Figure 49-L shows a cross-sectional schematic of an example of a transverse inductive proximity sensor 4800 having components formed from ELR materials and configured to produce an output signal indicative of the position of an object. The sensor 4800 comprises a coil 4810 wound around a core 4815, such as a ferrite core. The coil may be formed from ELR nanowires, ELR tapes, ELR thin films, ELR foils, or other formations of ELR material. When the sensor is brought near a ferromagnetic object 4805, the inductance of the coil is altered in a manner that depends on the distance d. The changed inductance may be detected by an inductance meter 4820. Therefore the distance d between a ferromagnetic object 4805 and the sensor 4800 can be determined by measuring changes in inductance. As shown in Figure 49-L, by coupling a non-ferromagnetic object 4930 to a ferromagnetic object such as a ferromagnetic disk 4935, the sensor 4800 may be used to indirectly determine the distance d to the non-ferromagnetic object 4930 using the same methods described above.

[00976] Although Figures 48-L and 49-L show two examples of a configuration of transverse inductive proximity sensors, the examples shown are for illustrative purposes only, and various other suitable configurations of a core (including ferromagnetic, ferrimagnetic and non-ferrite cores such as air or dielectric cores) and/or coils/windings (including solenoids, toroids, and other arrangements) are possible as would be appreciated. Various transverse inductive proximity sensors may comprise coils or

windings formed from ELR material. Also, various transverse inductive proximity sensors may utilize ELR coils, regardless of its precise mode of operation and measurement.

I.G. Hall Effect Position Sensors

[00977] Figure 50-L shows a schematic illustrating the operating principles of a Hall effect sensor 5000 having ELR components formed from ELR materials and configured to produce an output signal indicative of a magnetic field and/or the position of an object. As shown, in response to an input current I (e.g., a DC current) applied across two terminals of a conducting strip 5005, a magnetic field (B) produces a transverse Hall potential difference (V_H) across the other two terminals of the conductor. The output signal V_H (i.e., its sign and amplitude) depends on both the magnitude and direction of the magnetic field (B) and applied electric current (I). The conducting strip 5005 may be formed from ELR nanowires, ELR tapes, ELR thin films, ELR foils, or other formations of ELR material. Although not shown, the Hall effect sensor 5000 may be implemented in analog or bi-level form by integrating the sensor with interface circuits such as amplifiers or threshold electronics (such as a Schmitt trigger), respectively.

[00978] The output signal of a Hall effect sensor 5000 (or simply "Hall sensor") may be used to directly measure a magnetic field. The Hall effect sensor 5000 may also be combined with a magnetic field source such as a permanent magnet or other magnetic field source (e.g. solenoid or toroid) to detect position. In some examples of a Hall effect sensor, a permanent magnet or other magnetic field source is coupled to an object whose position is being measured. In such examples, the magnetic field detected by the Hall sensor therefore indicates the position of the object in relation to the Hall sensor, because the magnetic field that reaches the conductive strip will vary depending on the position of the object relative to the conductive strip. Figure 51-L shows one example of this general class of Hall effect position sensors. As shown, a magnet 5105 or other magnetic field source is placed into or on a float object 5110 so that the float moves up and down along a pole 5125 relative to the fixed Hall sensor 5120 located at the top of the pole.

[00979] As another example illustrated by Figures 52A-L and 52B-L, a Hall effect sensor may include a magnetic field source 5210 (such as a permanent magnet) that is interruptible by a moveable ferromagnetic object, such as a plate or vane 5215. As shown in Figure 52A-L, when the vane 5215 is in a first position that creates an air gap 5205 between the sensor and the magnet, the flux from the magnetic field source reaches the Hall sensor 5000 across the gap. As shown in Figure 52B-L, when the

vane 5215 is in a second position that occupies the gap 5205, the vane shunts the magnetic flux so that it does not reach the Hall sensor 5000. In such examples, the magnetic field detected by the Hall sensor therefore may indicate the position or displacement of an object coupled to the vane. The vane may have a linear or rotating motion. Such sensors may be used in automobile distributors, although many other applications are of course possible.

[00980] Various other sensors utilize the magnetoelectric transduction mechanism of a Hall sensor 5000. For example, sensors may employ multiple (e.g., four) Hall sensors configured in a bridge or other network arrangement and driven by a permanent magnet (or other magnetic field source) to measure linear or angular 3D position or motion. As another example, a Hall sensor may measure a current carried through a conductor by detecting a magnetic field produced by the current. As yet another example, a Hall sensor may be used to monitor disturbances to a magnetic field that result from bringing the sensor in proximity to a metallic structure, ferromagnetic or ferrimagnetic structure, or another type of object that disturbs the magnetic field.

[00981] Although Figures 50-L to 52-L show various examples of Hall effect sensors, the examples shown are for illustrative purposes only. Various other suitable configurations or geometries of a Hall effect sensor and/or other components (including permanent magnets, solenoids, toroids, and other magnetic field sources) used to characterize the position of an object or other types of stimulus may incorporate ELR materials. For example, various configurations may utilize a Hall effect sensor that comprises a conductive strip 5005 created from ELR nanowires, ELR tapes, ELR thin films, ELR foils, or other formations of the ELR material. As another example, various configurations may utilize a magnetic field source (e.g., solenoid or toroid) created from ELR nanowires, ELR tapes, ELR thin films, ELR foils, or other formations of ELR material.

[00982] Hall effect sensors may be used for numerous applications, including without limitation: rotating speed sensors (for anti-lock systems, automotive speedometers, disk drives, electronic ignition systems, tachometers, timing wheels, shafts, and gear-teeth), electronic compasses, electric motor control, position/motion sensing/switches, automotive ignition and fuel injection, fluid flow sensors, magnetic sensors, current sensors, and pressure sensors. Hall effect sensors may be included in, for example, automobiles, smart phones, printers, keyboards, industrial machinery, and some global positioning systems, and other applications, as would be appreciated.

I.H. Magnetoresistive Position Sensors

[00983] Various magnetoresistive sensors exploit anisotropic magnetoresistance characteristics of a conducting element. Magnetoresistive sensors may be used in many of the same configurations and applications as a Hall sensor, including as a proximity, position, or rotation detector. A magnetoresistive sensor detects changes in a magnetic field (such as a field generated by a permanent magnet or other magnetic field source such as a solenoid or toroid) by monitoring the resistance of the magnetoresistive conducting element, which changes in response to an altered magnetic field. Various configurations of magnetoresistive sensors may employ ELR components, such as ELR nanowires, ELR tapes, ELR thin films, ELR foils, or other formations of ELR material. For example, a magnetoresistive sensor may employ a magnetoresistive conductive element formed from an ELR thin film, ELR foil or other formation. As another example, a magnetoresistive sensor may employ a magnetic field source (such as a solenoid, toroid or other inductive winding) formed from ELR nanowires, ELR tapes, ELR thin films, and/or ELR foils.

I.I. Magnetostrictive Position Sensors

[00984] Various magnetostrictive sensors utilize a structure formed from magnetostrictive materials to convert magnetic energy into kinetic energy or vice versa. One example of a magnetostrictive position sensor uses ultrasonic waves to detect the position of a permanent magnet (or other magnetic field source) that is movable along the length of a waveguide. Such a system may employ one or more waveguides, magnetic field sources, piezoelectric sensors, and/or magnetic reluctance sensors. Various configurations of magnetoresistive sensors may comprise waveguides, magnetic field sources, magnetic reluctance sensors, or other ELR components formed from ELR nanowires, ELR tapes, ELR thin films, and/or ELR foils. Applications of magnetostrictive position sensors include hydraulic cylinders, injection molding machines, forges, elevators, mining, rolling mills, presses, and other devices that require fine resolution over long distances, and applications, as would be appreciated.

I.J. Radar Position Sensors

[00985] Various radar position sensors, such as pulse radar systems and continuous wave radar systems (including, inter alia, frequency modulated continuous wave radar, pulse Doppler, moving target indicator, frequency agile systems, synthetic aperture radar, inverse synthetic aperture radar, phased array radar), transmit pulses or continuous waves of high-frequency radio signals from an antenna and measure the

electromagnetic signals reflected from a target object to determine its location, range, altitude, direction, and/or speed. The systems may use the delay in the reflected signal and/or frequency shifts to determine the position and/or speed of a target object. Various configurations of radar position sensors may comprise transmitters, synchronizers, power supplies, oscillators, modulators, waveguides, duplexers/multiplexers, antennas, filters, receivers, pre- and post-processing and control components, and/or other ELR components formed from ELR nanowires, ELR tapes, ELR thin films, and/or ELR foils.

I.K. Other Position, Displacement, and Level Sensors

[00986] Other types of sensors that comprise ELR components formed at least in part from ELR nanowires, ELR tapes, ELR thin films, ELR foils, or other formations of ELR material may produce an output signal indicative of the position (e.g., proximity), displacement of an object and/or the level of a fluid. Non-exhaustive examples of other position, displacement, and level sensors may comprise ELR components that are formed at least in part from ELR material include the following: (1) optical proximity, displacement and position sensors that may include a light source, photodetectors (e.g., photodiodes, phototransistors, CCD arrays, CMOS imaging arrays), and light guidance and modification components (e.g., lenses, mirrors, optical fiber cables, filters), such as (a) optical bridge sensors, (b) optical proximity detectors that use polarized light, (c) fiber-optic sensors, (d) Fabry-Perot sensors, (e) grating sensors, (f) linear optical sensors, and (g) other optical position, displacement and level sensors; (2) ultrasonic position, displacement, and level sensors; (3) thickness and ablation sensors including (a) ablation sensors (e.g., break-wire gauges, radiation transducer sensors, light pipe sensors, capacitive or resonant ablation gauges), (b) thin film thickness gauging sensors (e.g., capacitive sensors employing electrodes, and optical sensors); (4) level sensors, including e.g., (a) resistive level sensors, (b) optical level sensors, (c) magnetic level sensors, (d) capacitive level sensors (e.g., having coaxial capacitive plates), and (e) transmission line level sensors (e.g., sensors that detect reflectance from a liquid-vapor interface); (5) pointing devices, including optical pointing devices, magnetic pickup pointing devices, and inertial and gyroscopic pointing devices; and (6) satellite navigation systems such as global positioning systems, global navigation satellite systems (GNSS), and so on.

II. OCCUPANCY AND MOTION SENSORS

[00987] In some examples, the sensor 3700 may be configured to provide an output signal that is indicative of the presence of people or animals in a monitored area

("occupancy") or the motion of an object. Such sensors may be used in toys, consumer electronics, security systems, surveillance systems, energy management systems, personal safety systems, appliances, and many other types of systems.

II.A. Capacitive Occupancy/Motion Sensors

[00988] Capacitive sensors may detect occupancy or human/animal motion by measuring the effects of human or animal body capacitance. Figure 53-L shows one example of a capacitive occupancy or motion sensor 5300. As shown, the sensor 5300 may comprise one or more capacitive plates 5305 or other capacitive structures (including, e.g., a test plate 5305a and reference plate 5305b), shields (such as driven shields), an input source, and a capacitance sensor 5330 or other sensors configured to detect changes in the capacitance between the various capacitive plates or elements (e.g., changes from a known reference capacitance Cref 5320) caused by the presence of a human 5325 or animal. The change in capacitance may result because the human 5325 forms coupling capacitances with its surroundings, including coupling capacitances to the test plate 5305a and reference plate 5305b (C1 5310a and C2 5310b, respectively). Some or all of these components may be formed at least in part from ELR nanowires, ELR tapes, ELR thin films, ELR foils, or other formations of ELR material.

II.B. Triboelectric Detectors

[00989] Various triboelectric sensors detect motion of a human, animal or other object by detecting disturbances in a static or quasi-static electrical field (e.g., 5415) that are caused by a moving human or animal carrying a surface charge caused by the triboelectric effect (or colloquially, "static electricity"). Figure 54-L shows one example of a monopolar triboelectric motion detector 5400. As shown, triboelectric sensors may comprise one or more electrode plates 5405 or other electrode structures, and an impedance converter 5410 or other post-processing electronics for detecting changes in the charge on the electrode plates/structures caused by the movement of a human 5420, animal or other charge carrier. These components may be formed at least in part from ELR nanowires, ELR tapes, ELR thin films, ELR foils, or other formations of ELR material.

II.C. Optoelectric Motion Sensors

[00990] Various optoelectric motion sensors detect motion of a human, animal or other object in a monitored area by detecting visible or infrared light reflected or emanated from the object that creates an optical contrast between the object and its surroundings.

The light detected may originate from a light source (such as a light emitting diode, daylight, moonlight, incandescent lamp, laser, etc.) or from the moving object itself (e.g., mid- and far-IR emission from a human body). Figure 55-L is a schematic that illustrates the general structure of an optoelectronic motion sensor 5500. As shown, the sensor may comprise one or more focusing devices 5505 (e.g., lenses including pinhole lenses, facet lenses, Fresnel plastic lenses, and mirrors including parabolic mirrors, etc.); one or more light detecting elements 5510 (e.g., bolometers, thermopiles, pyroelectric elements, photovoltaic cells, photoconductive cells, photo resistors, PVDF film, CCD sensors, CMOS imaging sensors, etc.); and post-processing electronics 5515, such as amplifiers and comparators, configured to post-process the signal produced by the light detecting elements. Some or all of these components may be formed at least in part from ELR materials. For example, as described in greater detail herein, various light detecting elements may be formed at least in part from ELR nanowires, ELR tapes, ELR thin films, ELR foils, or other formations of ELR material. As shown, when an object 5525 (such as a person) moves across the field of view of the focusing device 5505 (as shown by arrow), the object's image 5520 moves and thereby creates a photon flux on the light detecting element 5510 different from the photon flux caused by an image of the static surroundings. The light sensitive element responds with a changed or disturbed voltage. The disturbance is detected by the post-processing electronics. Optoelectronic detectors may be used in security systems, energy management, consumer electronics, toys, etc.

II.D. Optical Presence Sensors

[00991] Various optical presence sensors detect the presence of an object in a monitored area by detecting an alteration in the amount of light that is reflected or absorbed by the object. Figure 56-L is a schematic that illustrates an example of an optical presence detector 5600. As shown, the optical presence detector includes a light source or emitter 5615 (such as an LED), driven by a driver 5625, that produces a light beam in the field of view of a light sensor 5620 (such as those described herein). The static background reflects a particular amount of light back to the light sensor, which creates a background output signal. When an object 5640 appears in the field of view of the light sensor 5620, it reflects or absorbs light in a manner different than the static surroundings. The light sensor and a light-to-voltage converter 5630 therefore produce a detectable output, different from the normal background signal, in response to the different light reflectance/absorption of the object. As shown, the optical presence detector may include various focusing and guidance elements such as a lens 5605 and a

light pipe 5610 to produce the light beam 5645 and/or receive reflected light. Also, the sensor may include a processor 5635, configured to drive the light source 5615 and process the output signal of the light sensor 5620. Some or all of these components may be formed at least in part from ELR materials. For example, as described in greater detail herein, various light sensor elements may be formed at least in part from ELR nanowires, ELR tapes, ELR thin films, ELR foils, or other formations of ELR material. Such detectors may be used in robots, hand dryers, sinks, toilets, light switches, and other consumer, commercial, and household products.

II.E. Pressure Motion Sensors

[00992] Various pressure motion sensors detect intrusions or other motion in a closed, controlled space by monitoring variations in air pressure that result from sudden movement of doors, windows, people, or other objects. Figure 57-L is a cross-sectional schematic that illustrates an example of an air pressure-gradient sensor 5700. As shown, air-pressure-gradient sensor 5700 may include a chamber 5725 formed in part from two opposing walls: a metallic or metalized flexible membrane 5710 or diaphragm (such as a metalized plastic membrane or metal foil) and a rigid metallic or metalized plate 5705, which includes a vent hole 5715. The two metallic surfaces, which may be formed from ELR materials, together have a coupling capacitance. Therefore, deflections of the membrane 5710 (from a neutral position shown with dashed line) caused by sudden changes in air pressure may be determined using a capacitance sensor 5720, e.g., a sensor that uses the capacitive displacement sensing systems and methods described herein. Of course, as described above, with respect to capacitive displacement sensors, other components of such motion sensors may be formed from ELR materials. In other examples, the air pressure-gradient sensor 5700 may include other types of displacement sensors to determine the deflection of the membrane, such as other displacement sensors described herein. In such examples, the membrane and/or rigid plate may not be metallic or metalized.

II.F. Other Occupancy and Motion Detectors

[00993] Other types of sensors that comprise ELR components formed at least in part from nanowires, tapes, thin films, foils, or other formations of ELR material may produce an output signal indicative of occupancy or motion. Various examples of other occupancy, presence, or motion sensors may comprise components that are formed at least in part from ELR material include: radar systems (as described herein), other air pressure/pressure-gradient sensors, acoustic sensors, photoelectric sensors that detect

an interrupted light beam, pressure mats or other pressure-sensitive surfaces, stress or strain detectors embedded in a protected area, switch sensors including magnetic switches, vibration detectors, infrared motion detectors, ultrasonic detectors, video motion detectors, face recognition systems, laser detectors, alarm sensors, Reed switches, stud finders, triangulation sensors, wired gloves, and Doppler radar sensors.

III. VELOCITY AND ACCELERATION SENSORS

[00994] In some examples, the sensor 3700 may be a single- or multi-axis velocity sensor or accelerometer configured to provide an output signal that is indicative of the velocity or acceleration of an object, respectively. A velocity sensor may measure the linear or angular speed or rate of motion of an object. An accelerometer may measure the coordinate acceleration or proper acceleration of an object, e.g., by measuring weight per unit of test mass or specific force. Accelerometers may be used to determine, inter alia, orientation, coordinate acceleration (i.e., change of velocity of an object in space), vibration, shock, and falling. Multiple accelerometers may be used to detect differences in acceleration, e.g., as gradiometers.

[00995] Velocity sensors or accelerometers may be used in numerous applications, including without limitation: automobiles (e.g., for acceleration or velocity measurements, evaluation of engine/drive train and braking systems, electronic stability control systems, airbag deployment), trains, vulcanology, commercial or industrial equipment, vibration measurements/monitoring, seismic activity measurements, inclination measurements, gravimeters, machinery health monitoring, aircraft/avionics equipment, inertial navigation or guidance systems, medical equipment, and consumer products, including video game systems, sports equipment, and other portable electronics, such as mobile phones, camcorders and cameras (e.g., for image stabilization and/or orientation determinations), smart phones, audio players, tablet computers, laptop computers, personal digital assistants, and other mobile computers.

[00996] In some examples, position/displacement, velocity, and/or acceleration sensors may be used interchangeably due to the mathematical relationship between these quantities. As a first example, in low-frequency or low-noise applications, the displacement sensors and methods described elsewhere herein may be used for sensing velocity and acceleration. Additional post-processing, e.g., differentiation, may be performed on an output signal of the displacement sensor to determine one or more of the signal's mathematical derivatives that indicate velocity or acceleration. As a second example, in medium-frequency or medium-noise applications, the velocity

sensors and methods described herein may be used for sensing acceleration. Additional post-processing, e.g., differentiation, may be performed on an output signal of the velocity sensor to determine the signal's mathematical derivative that that indicates acceleration. As a third example, the acceleration and/or velocity sensing systems and methods described herein may be used to determine velocity and/or position/displacement, respectively. Additional post-processing, e.g., mathematical integration, may be performed on the output signals of an acceleration and/or velocity sensor to determine the velocity and/or position/displacement of an object, respectively.

III.A. Electromagnetic Velocity Sensors

[00997] Figure 58-L shows a schematic illustrating the operating principles of an electromagnetic velocity sensor. As shown, the sensor 5800 comprises two or more induction coils 5810 and 5815 connected in series-opposite direction around a moveable permanent magnetic core 5805; the coils may be partially or wholly formed from ELR material. Under Faraday's law, moving the magnetic core within a coil induces a voltage in the coil proportional to the velocity of the core. Therefore, the output voltage across the two coils may be measured to determine the velocity of the core, and therefore the velocity of an object coupled to the core. The arrangement of coils shown is intended to be illustrative only and other geometries may be employed, including using one or more coils wrapped around a moveable rotary magnetic core for angular velocity measurements. The sensor shown may be used, for example for sensing the velocity of vibration.

III.B. Accelerometers Having Proof Masses

[00998] As illustrated in Figure 59-L, various accelerometers 5900 determine acceleration (a) of an object 5905 coupled to the housing 5910 of the accelerometer by measuring the displacement of a relatively large moveable seismic, inertial or proof mass 5915 having a known weight and coupled to the accelerometer's housing by springs 5920, cantilevers, hinges or other elastic elements. To measure the displacement, the accelerometer 5900 may use one or more displacement sensors, such as the displacement sensors described herein. In such examples (including examples described further herein), the proof mass, components of a displacement sensor, and/or other components may be formed in whole or in part from ELR materials.

III.C. Capacitive Accelerometers

[00999] Various capacitive accelerometers determine the displacement of a proof mass, and therefore the acceleration of an object, by using capacitive displacement conversion

methods, e.g., using principles and systems similar to those described herein with respect to capacitive displacement sensors. As shown in Figure 60-L, in such examples, the sensor 6000 may comprise (1) a moveable proof mass 6005 supported by springs or other elastic elements 6020 (such as silicon springs) and configured to move within a housing 6025 of the sensor, and (2) two or more capacitive plates 6015, 6010, 6005 or elements, which may include the proof mass 6005 itself, moveable capacitive plates or elements, e.g., connected to the moveable proof mass (not shown), and/or stationary capacitive plates or elements 6005, 6010 whose positions are fixed with respect to the accelerometer's housing 6025. Any or all of these components or other components of the sensor 6000 may be formed in whole or in part from ELR materials. The movement of the proof mass during acceleration causes the capacitances between the various capacitive elements (e.g. C1, C2) to change due to the altered relative positions of the capacitive elements. The changed capacitances may be detected in any suitable way (including differential techniques and other methods described herein) and thus used to derive the displacement of the proof mass, which in turn may be used to determine the acceleration of an object 6030 coupled to the accelerometer's housing 6025. In some examples, a capacitive accelerometer may be micromachined, e.g., using MEMS technologies or other techniques.

III.D. Piezoresistive Accelerometers

[001000] Various piezoresistive accelerometers determine the displacement of a proof mass, and therefore the acceleration of an object coupled to the accelerometer, by using piezoresistive elements. In such examples, the sensor may comprise (1) a moveable proof mass supported by springs, hinges, or other elastic elements and configured to move within the housing of the accelerometer, and (2) piezoresistive strain gauge elements that measure strain in the spring or elastic elements caused by the displacement of the proof mass (further discussion of piezoresistive strain gauges is provided herein). Any or all of these components may be formed in whole or in part from ELR materials. In some examples, a piezoresistive accelerometer may be micromachined, e.g., using MEMS technologies or other techniques.

[001001] Figure 61-L shows an exploded view of one example of a piezoresistive accelerometer 6100. As shown, recesses within a lid layer 6110 and a base layer 6105 form a cavity within which the proof mass 6115 can move in response to acceleration. In an inner layer of silicon, the proof mass 6115 is coupled to a support ring 6120 via an elastic hinge 6125. Integrated strain gauges 6130 on the hinge provide output signals

from the terminals that indicate the displacement of the proof mass and therefore the acceleration of the housing.

III.E. Piezoelectric Accelerometers

[001002] Various piezoelectric accelerometers determine the displacement of a proof mass, and therefore the acceleration of an object coupled to the accelerometer, by using piezoelectric elements. As shown in Figure 62-L, in such examples, the sensor 6200 may comprise (1) a moveable proof mass 6205 configured to move relative to the housing 6220 of the accelerometer, and coupled to the housing via a spring, hinge or other elastic member 6210 and (2) piezoelectric elements 6225, such as elements formed from ELR materials, quartz crystal, barium titanante, lead zirconite titanate, lead metaniobite, or other ceramic piezoelectric materials, and configured to respond to movements of the proof mass (e.g., by shearing, compressive, bending, or other types of movement) with an electrical signal. Any or all of these components may be formed in whole or in part from ELR materials. As shown, when the housing of the accelerometer accelerates, it moves relative to the proof mass, which exerts force (e.g., a shearing, compressive or bending force) on the piezoelectric elements, causing an electrical output signal indicative of the acceleration. Although a compressive force is shown, in other configurations, the piezoelectric element may experience other types of forces from the proof mass. In some examples, a piezoelectric accelerometer may be micromachined, e.g., using MEMS technologies or other techniques. In some examples, the piezoelectric elements may be piezoelectric films disposed on the moveable proof mass and/or on springs, hinges, or micromachined cantilevers that support the proof mass.

III.F. Heated Plate Accelerometers

[001003] Various heated plate accelerometers determine the displacement of a heated proof mass, and therefore the acceleration of an object coupled to the accelerometer, by using temperature sensors to detect temperature fluctuations caused by movement of the proof mass. Figure 63-L shows one example of a heated plate accelerometer 6300 (with a roof component omitted) that comprises (1) a moveable proof mass 6305 configured to move relative to the housing of the accelerometer and supported by a cantilever beam 6310 or hinge, (2) a heating element 6315 (such as a resistor) configured to heat the proof mass to a defined temperature, (3) one or more heat sinks 6320 separated from the proof mass by a thermally conductive gas 6325 and configured to receive heat from the proof mass through the gas, (4) one or more

temperature sensors 6330, such as thermopiles, disposed in, on, or near the cantilever beam or hinge (or another component) and configured to determine temperature fluctuations in the cantilever beam (or another component) that result from the proof mass being displaced from its neutral position. Any or all of these components or other components may be formed in whole or in part from ELR materials.

[001004] In still other examples, gas heated by a resistor or other heating element may be used as the seismic mass. The accelerometer may use thermopiles or other temperature sensors to detect temperature fluctuations caused by the movement of the heated gas that results during acceleration (i.e., from a convective force). In such examples, the heating element, temperature sensors, and/or other components may be formed in whole or in part from ELR materials.

III.G. Other Types of Velocity Sensors and Accelerometers

[001005] Other types of sensors that comprise ELR components formed at least in part from ELR nanowires, ELR tapes, ELR thin films, ELR foils, or other formations of ELR material may produce an output signal indicative of velocity or acceleration. Non-exhaustive examples of velocity sensors and accelerometers (including gyroscopes and gravitational detectors such as inclinometers or tilt detectors) that may comprise components that are formed at least in part from ELR material include the following types of velocity or acceleration sensors: satellite navigation systems such as global positioning systems and global navigation satellite systems, rotor gyroscopes (such as magnetic levitation gyroscopes), gravimeters (including (a) gravimeters that use a magnetically levitated sphere, and that may use coils or spheres formed from ELR material, and (b) gravimeters that comprise a spool and magnet both covered at least in part with ELR material), monolithic silicon gyroscopes, optical gyroscopes, conductive gravitational sensors (e.g., mercury switches, electrolytic tilt sensors), inclination sensors employing an array of photodetectors, piezoelectric sensors, micromachined capacitive (MEMS) sensors, shear mode sensors, surface bulk micromachined capacitive sensors, bulk micromachined piezoelectric resistive sensors, capacitive spring mass base sensors, electromechanical servo (servo force balance) sensors, null-balance sensors, strain gauge sensors, resonance sensors, thermal sensors (e.g., submicrometer CMOS process), magnetic induction sensors, variable reluctance sensors, optical sensors, surface acoustic wave (SAW) sensors, laser sensors, DC response sensors, triaxial sensors, modally tuned impact hammer sensors, pendulating integrating gyroscopic sensors, and seat pad sensors. Other, non-exhaustive examples of sensors that may be

formed at least in part from ELR material include the following types of sensors: (1) free fall sensors; (2) inclinometers; (3) laser rangefinders; (4) linear encoders; (5) liquid capacitive inclinometers; (6) odometers; (7) rotary encoders; (8) Selsyn sensors; (9) sudden motion sensors; (10) tachometers; (11) ultrasonic thickness gauges; and (12) SONAR sensors.

IV. FORCE, STRAIN, AND TACTILE SENSORS

[001006] In some examples, the sensor 3700 may be a sensor that comprises ELR material and is configured to provide an output signal that is indicative of a force, strain, and/or touch applied to an object. Like other types of sensors, force or strain sensors comprising ELR material may be (1) quantitative sensors configured to measure force or strain and reflect the measured value in an electrical output signal, or (2) qualitative sensors configured to detect a force or strain in excess of (or lower than) a threshold value.

IV.A. Piezoelectric Cables

[001007] Figure 64-L shows one example of a piezoelectric cable that may be used to provide an output signal that is indicative of a force, strain, and/or or touch. As shown, the coaxial piezoelectric sensor 6400 includes a piezoelectric material 6405, such as a piezoelectric polymer or piezoelectric powder, that forms part of the dielectric between the center conductor core 6415 and the outer conductor sheath 6410 of a coaxial cable. When the cable is subjected to a compressive or stretching force, it produces a responsive charge or voltage that is picked up by the conductors. Such cables may be used for various purposes including monitoring vibration and automobile traffic. These cables may be adapted such that the center conductor core and/or outer conductor shield is formed in whole or in part from ELR materials.

IV.B. Complex Force Sensors (Including Load Cells)

[001008] Complex force sensors, or force cells, may (1) transduce an unknown force into an intermediary signal using a first transducer, and (2) convert the intermediary signal into an electrical output signal using a second transducer (i.e., a direct sensor). Figure 65A-L shows one example of a complex force sensor 6500 that has a spring 6510 or other force-to-displacement transducer that transduces an applied force 6505 into a displacement; the displacement is then measured by a displacement sensor 6515, such as a linear variable differential transformer sensor or any other type of displacement sensor, as described above. Figure 65B-L shows a second example of a complex force sensor 6550 that has a bellows 6555, diaphragm, or other force-to-pressure transducer

that transduces an applied force into a pressurized fluid. The generated pressure of the fluid is then measured by a pressure sensor 6560, such as those described herein. In a third example, not shown, an unknown force, via mechanical components (such as an elastic member), deforms one or multiple strain gauges (described herein), which may be arranged in a bridge configuration. The strain gauges convert the deformations into an electrical signal.

[001009] Other complex force sensors/force cells include: those that operate using different operating principles (cantilever, bending beam, compression, tensile, universal, shear, torque, hollow) and/or with different constructions (e.g., bending beam, parallel beam or binocular beam, canister, shear beam, single column, multi-column, pancake, load button, single-ended shear beam, double-ended shear beam, "s" type, inline rod end, digital electromotive force, diaphragm/membrane, torsion ring, bending ring, proving ring, or load pin). Any complex force sensors, such as those described herein may use ELR materials, e.g., in a direct sensor (such as those described herein) that converts an intermediary signal into an electrical output signal.

IV.C. Strain Gauges

[001010] Various strain gauges measure the strain (deformation) of an object by producing and/or measuring piezoresistive changes in resistance that result from the deformation. Figure 66-L shows one example of a wire strain gauge 6600 that may be used to produce an output signal that is indicative of a strain. As shown, the strain gauge comprises a resistive element 6610 (e.g., a wire or foil) bonded with an elastic insulating backing 6605, which may be adhered or otherwise connected to an object that experiences an applied strain. The changed resistance may be measured using a Wheatstone bridge or other resistance sensor. The resistive element and/or resistance sensor may be formed from ELR materials. Although various shapes may be used, often the resistive element is formed in a serpentine format having multiple longitudinal segments that are much longer than the transverse segments. Multiple strain gauges may be arranged (e.g., to measure strains in different axes); they may also be arranged in bridge configurations. In some examples, strain gauges may also include temperature compensation components configured to compensate for resistive changes that result from changes in temperatures. ELR materials may also be incorporated into other types of strain gauges, including semiconductor strain gauges.

IV.D. Switch Tactile Sensors

[001011] Various contact switch tactile sensors detect a contact force at a defined point. Figure 67-L shows one example of a switch tactile sensor 6700. As shown in the cross-sectional view of Figure 67-L, the sensor 6700 comprises a grounded flexible or depressible conductive surface 6705 (e.g., a flexible foil, a film such as Mylar or polypropylene printed with conductive ink) separated from fixed conductors 6710 (such as a foil, conductive trace, or conductive ink printed or otherwise disposed on a rigid backing 6740) by a separator 6735 that has holes 6720. The fixed conductor is coupled to a pull-up resistor 6730. When an applied force (f) from an object 6740 deflects the flexible conductor down through a hole, the flexible conductor contacts a fixed conductor 6710b and grounds the pull-up resistor to drive the output voltage down. If more than one sensing area is provided, they may be multiplexed by a multiplexer 6725. Of course, other configurations could be utilized to achieve a similar on/off switching effect (e.g., a flexible conductor, not a fixed conductor, could be connected to a pull-up resistor; two flexible conductive surfaces could be used instead of fixed conductors). In any such switch configuration, the pull-up resistor, flexible conductive surfaces, fixed conductors, and/or any other components may be formed in whole or in part from ELR materials.

IV.E. Piezoresistive Tactile Sensors

[001012] Various piezoresistive tactile sensors detect a contact force at a defined point by detecting changes in the resistance of a piezoresistive element that result from the contact force. Figure 68-L shows a cross-sectional view of one example of a piezoresistive tactile sensor 6800. As shown, the sensor 6800 includes one or more conductive pushers 6805 separated from a conductive plate 6815 or other conductive surface by a force-sensitive resistor 6810 such as a conductive elastomer or pressure-sensitive ink. An applied force (f) on a conductive pusher 6805a may result in a change in the contact area of the resistor and/or a change in the thickness of the resistor, either of which results in a change in the resistance between the pusher and plate, which may be detected and processed to determine that a contact force occurred. Figure 69-L shows another example of a piezoresistive tactile sensor 6900. As shown, the sensor includes two or more electrodes 6905, 6910, which may be formed in an interdigitized or other configuration, and disposed on a plastic or other film carrier (not shown) that puts the electrodes in contact with a semiconductive polymer 6915 that exhibits force-sensitive resistance. In any piezoresistive tactile sensors, resistive elements, conductive elements and/or other components may be formed in whole or in part from ELR materials.

IV.F. Capacitive Tactile Sensors

[001013] Various capacitive tactile sensors detect a contact force at a defined point by detecting a change in capacitance caused by either (1) a changed geometry of capacitive elements (e.g., changed distances between the elements or changed surface area of the elements) within the sensor due to an applied mechanical force, or (2) the presence of a conductive object (e.g., a human finger) that capacitively couples to capacitive elements within the sensor, in a manner that may vary with the distance between the object and the capacitive elements. All types of capacitive tactile sensors, including those described in further detail herein, may comprise components, including capacitive elements such as electrodes and other conductors, which are formed from ELR materials.

[001014] Generally speaking, the first class of capacitive sensors may be understood as comprising a force-to-displacement transducer (e.g., a button coupled to a spring or another type of elastic component, such as an elastomer-filled chamber) that, in response to an applied force, produces a displacement of a capacitive element that the sensor measures using a capacitive displacement sensor. The capacitive displacement sensor used may be one of those capacitive displacement sensors described herein, e.g., in Figures 41-L to 45-L. Figure 70-L shows a cross-sectional view of an example of a capacitive tactile sensor 7000 that includes a first flexible or depressible conductive electrode 7005 or capacitive element separated by an elastic dielectric 7010 from a second conductive electrode 7015 or capacitive element. The second electrode may be patterned or otherwise disposed on a rigid base 7020. The dielectric used may have a high permittivity. When a force (f) 7030 is applied by an object 7025, the first flexible electrode 7005 may deform, altering the capacitance between the two electrodes. The sensor 7000 may detect the changed capacitance and analyze it to determine that a force was applied. The changed capacitance may be measured in any fashion known in the art, including measuring a time delay caused by a variable capacitance or by using the sensor 7000 as part of an oscillator and measuring the frequency response of the oscillator.

[001015] Figure 71A-L shows another example of a capacitive tactile sensor 7100 that comprises a pair of electrodes 7105a, 7105b disposed on or otherwise coupled to the underside of a touch surface 7110, such as a glass or clear polymer touch screen surface. The electrode 7105b is grounded. The two electrodes may be arranged in an interdigitized configuration, or any other suitable configuration. The pair of electrodes

has a baseline coupling capacitance Ca, which is monitored by a capacitance sensor 7120 that uses methods known in the art, such as those described above, to measure the capacitance. When a conductive object 7115 (e.g., a finger) approaches the surface, it capacitively couples with the first electrode 7105a and the second electrode 7105b (as shown by Cat and Cbt), which alters the total capacitance measured by the capacitance sensor 7120. The coupling capacitances between the object and the two electrodes 7105 may be a function of the distance of the object from the electrodes and the force being applied (if the conductive object is deformable). Although only two electrodes are shown, an array, grid (e.g., of rows and columns), or any other configuration of multiple electrodes may be utilized. If multiple electrodes are used, various capacitances between various combinations of the multiple electrodes may be monitored to detect the position of tactile contact.

[001016] Figure 71B-L shows another example of a capacitive tactile sensor 7150 that comprises an ungrounded electrode 7105 disposed on or otherwise coupled to the underside of a touch surface, such as a glass or polymer touch screen surface. The electrode has a baseline coupling capacitance to ground (Ca), which is monitored by the capacitance sensor 7120. When a conductive object 7115 (e.g., a finger), which has its own coupling capacitance to ground (Cgnd), approaches the surface, it forms a coupling capacitance with the electrode 7105 (as indicated by Cat), which alters the total capacitance measured by the capacitance sensor 7120. The coupling capacitance between the electrode 7105 and the conductive object 7115 is a function of the distance of the object from the electrode and the force being applied (if the conductive object is deformable). Although one electrode is shown, an array, grid (e.g., of rows and columns), or any other configuration of multiple electrodes may be utilized, and the capacitances between multiple electrodes and ground may be monitored to detect the position of tactile contact.

IV.G. Other Types of Force, Strain, and Tactile Sensors

[001017] Non-exhaustive examples of force, strain, and tactile sensors that may comprise components that are formed at least in part from ELR material include: (1) pressure-sensitive mats, (2) sensors that balance an unknown force against the gravitational force of a known mass, (3) sensors that determine acceleration of a known mass to which an unknown force is applied, (4) sensors that balance an unknown force against an electromagnetically generated force, (5) sensors that transduce an unknown force into a fluid pressure and then measure the resultant fluid pressure, (6) any

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CECI EST LE TOME 1 DE 2
CONTENANT LES PAGES 1 À 248

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JUMBO APPLICATIONS/PATENTS

THIS SECTION OF THE APPLICATION/PATENT CONTAINS MORE THAN ONE VOLUME

THIS IS VOLUME 1 OF 2
CONTAINING PAGES 1 TO 248

NOTE: For additional volumes, please contact the Canadian Patent Office

NOM DU FICHIER / FILE NAME :

NOTE POUR LE TOME / VOLUME NOTE:

What is claimed is:

1. A computing device, comprising:

a component formed at least in part of a modified extremely low resistance (ELR) material, wherein the modified ELR material comprises:

an ELR material having a face and a crystalline structure, wherein the face is parallel to an a-axis of the crystalline structure, and

a modifying material adjacent to the face of the ELR material, wherein the modifying material comprises a substantially pure form of a metal, or an oxide of the metal, wherein the metal is selected from the group consisting of: chromium, copper, bismuth, cobalt, vanadium, titanium, rhodium, beryllium, gallium, and selenium.

2. An electrical device, comprising:

a component formed at least in part of a modified extremely low resistance (ELR) material, wherein the modified ELR material comprises:

an ELR material having a face and a crystalline structure, wherein the face is parallel to an a-axis of the crystalline structure, and

a modifying material adjacent to the face of the ELR material, wherein the modifying material comprises a substantially pure form of a metal, or an oxide of the metal, wherein the metal is selected from the group consisting of: chromium, copper, bismuth, cobalt, vanadium, titanium, rhodium, beryllium, gallium, and selenium.

3. A mechanical device, comprising:

a component formed at least in part of a modified extremely low resistance (ELR) material, wherein the modified ELR material comprises:

an ELR material having a face and a crystalline structure, wherein the face is parallel to an a-axis of the crystalline structure, and

a modifying material adjacent to the face of the ELR material, wherein the modifying material comprises a substantially pure form of a metal, or an oxide of

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the metal, wherein the metal is selected from the group consisting of: chromium, copper, bismuth, cobalt, vanadium, titanium, rhodium, beryllium, gallium, and selenium.

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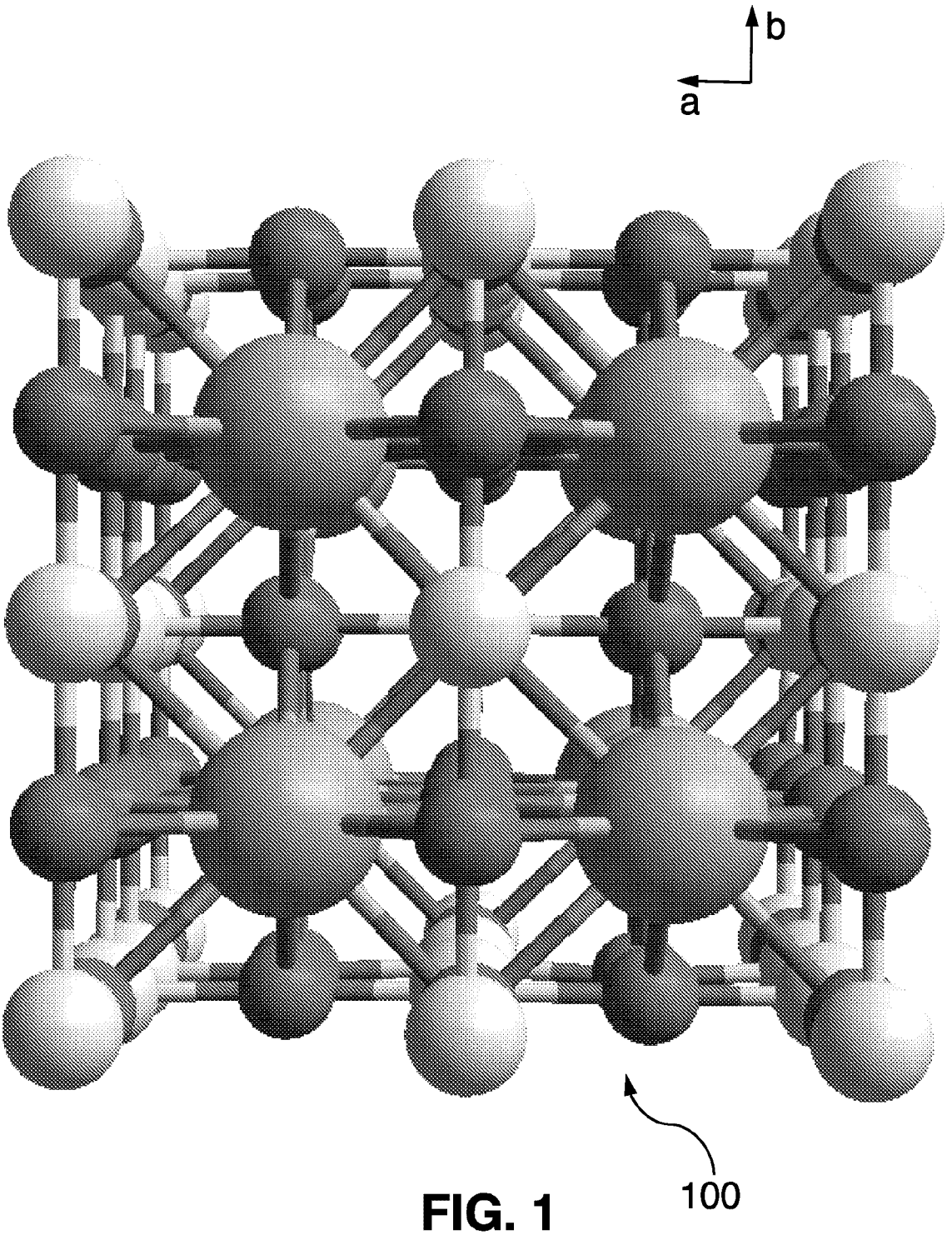


FIG. 1

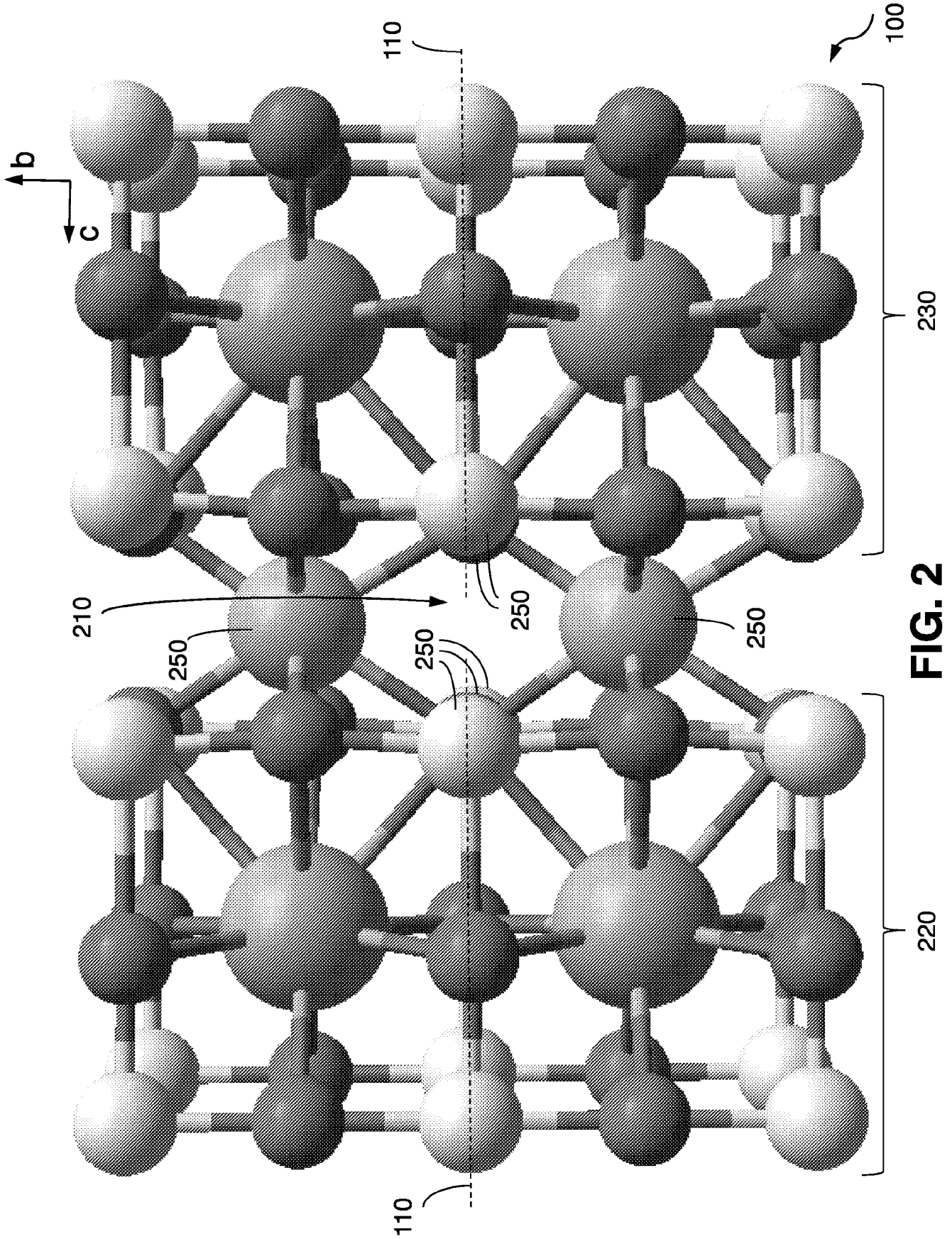


FIG. 2

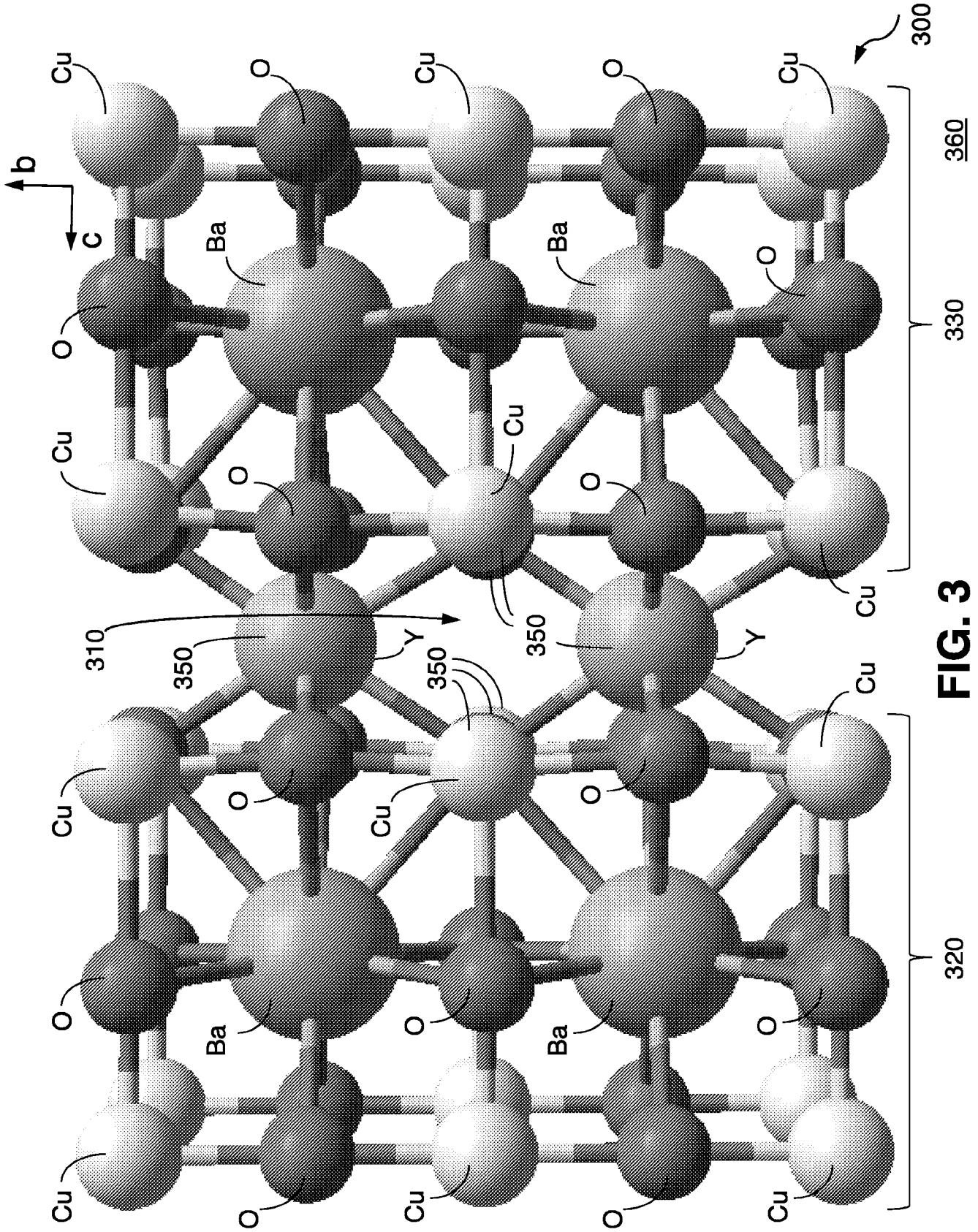


FIG. 3

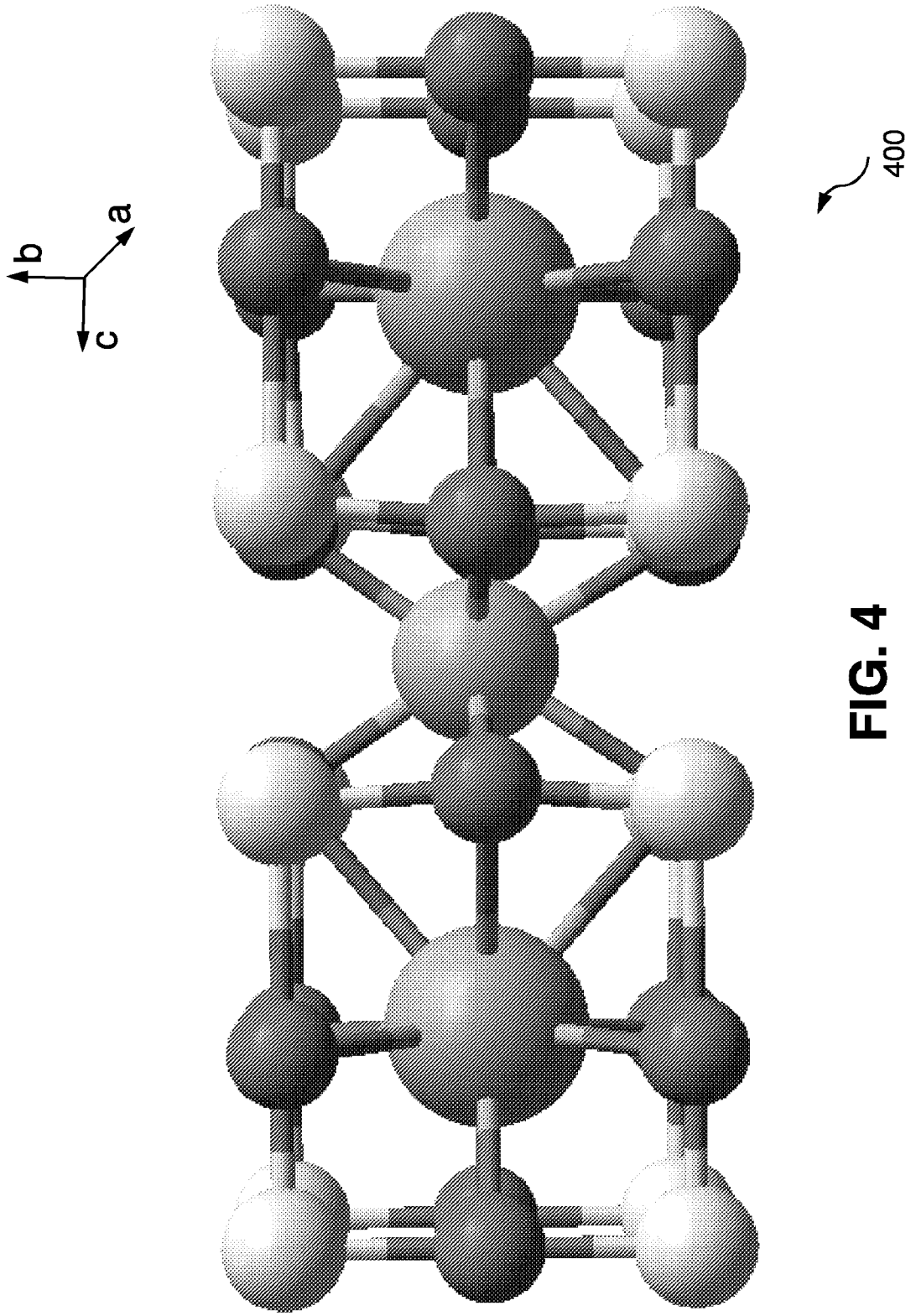


FIG. 4

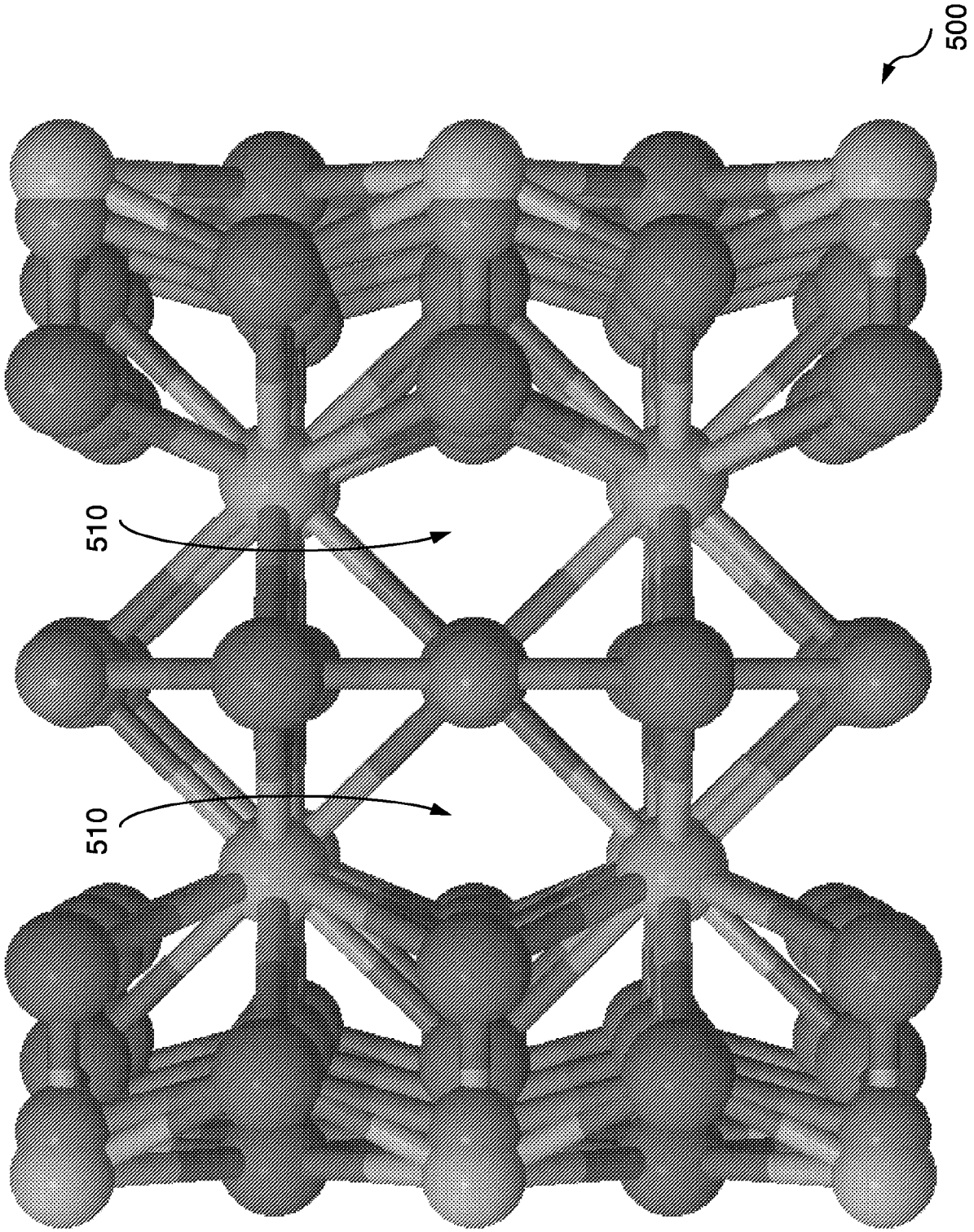


FIG. 5

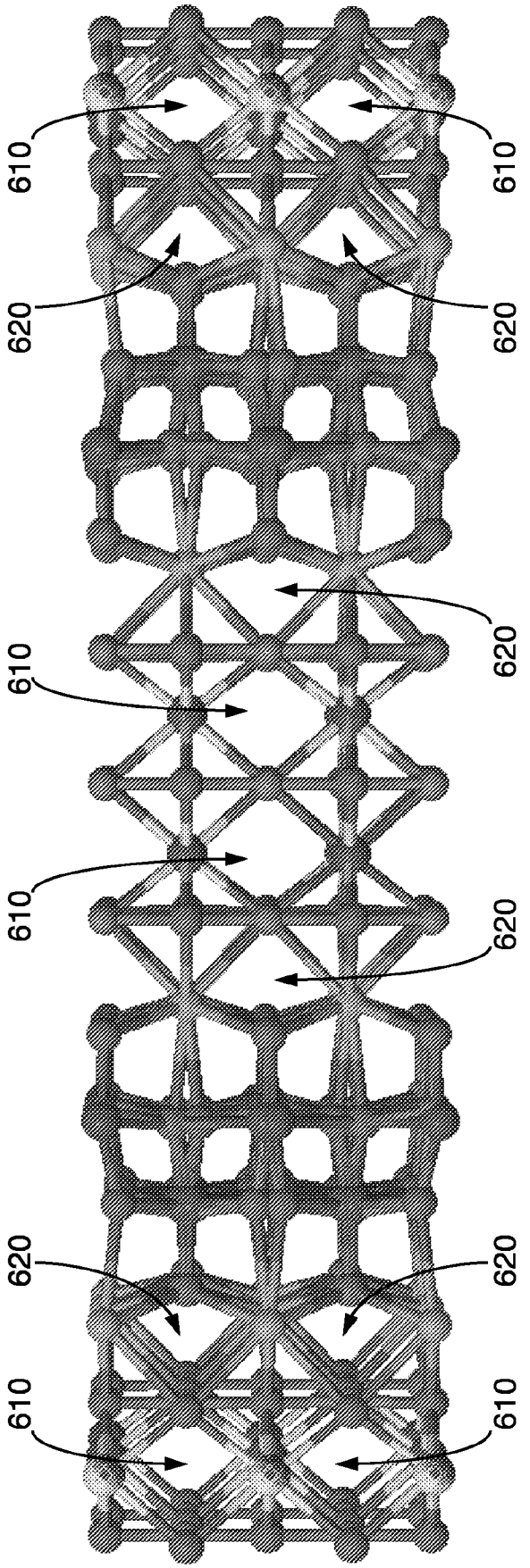


FIG. 6

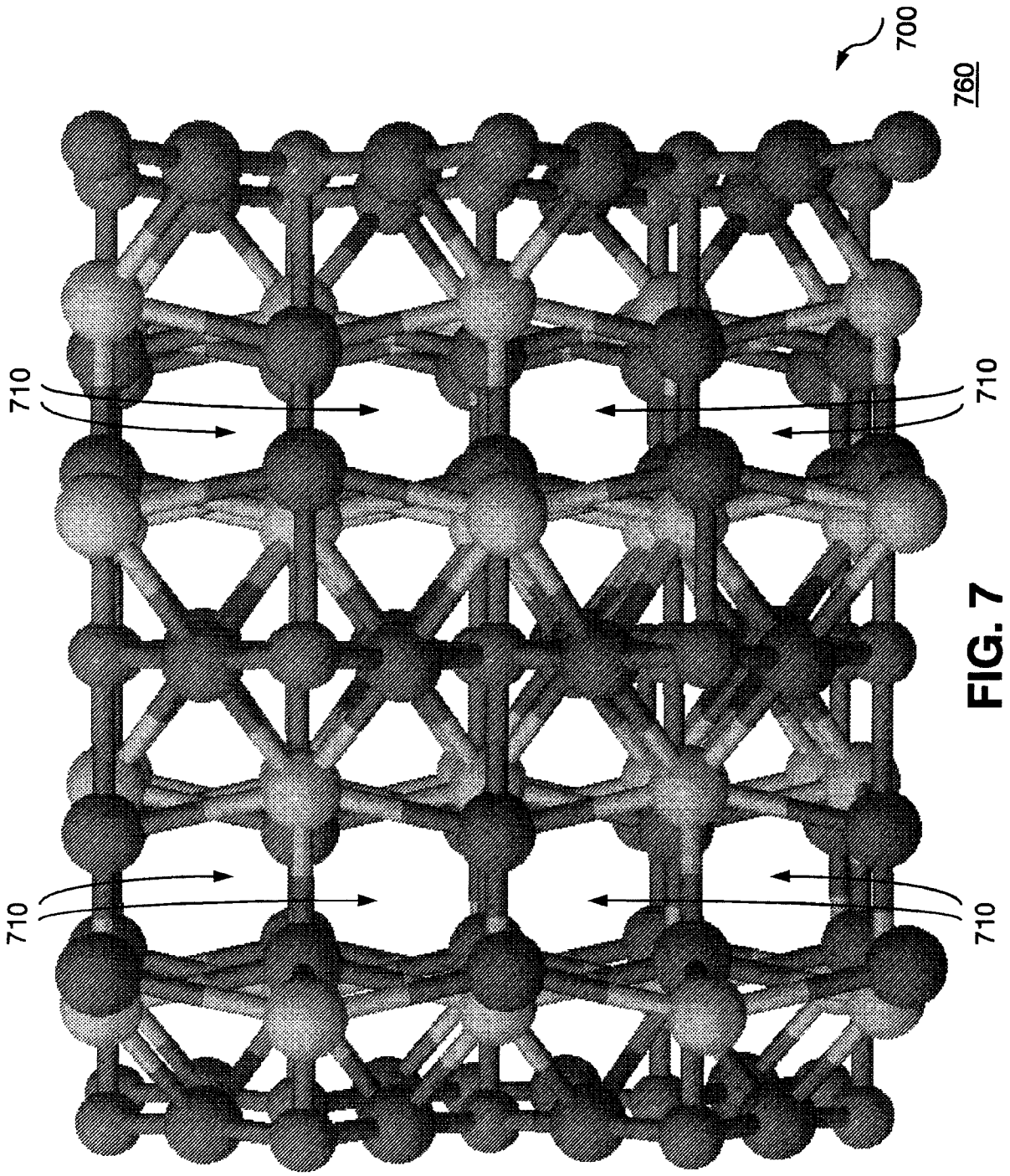


FIG. 7

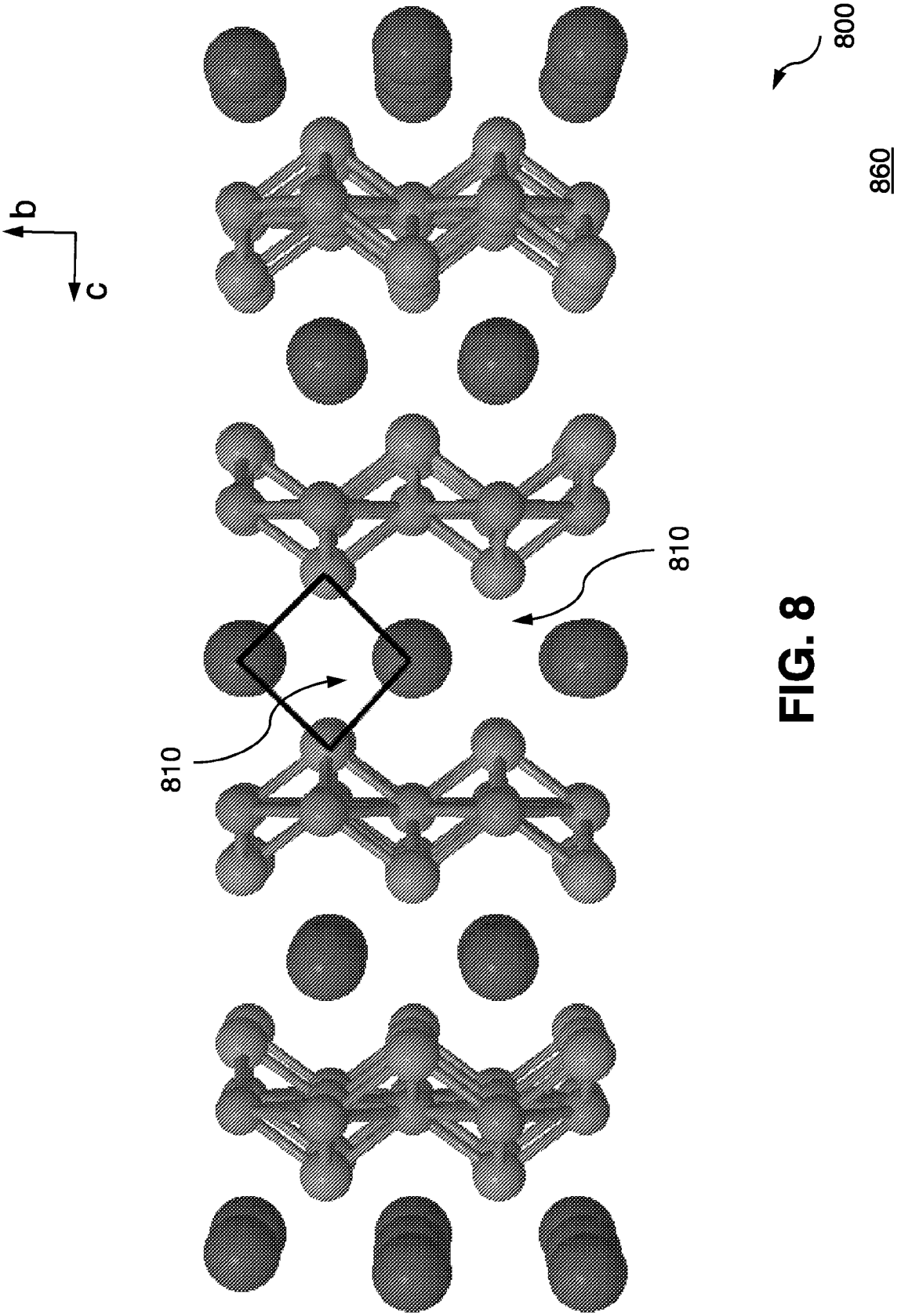


FIG. 8

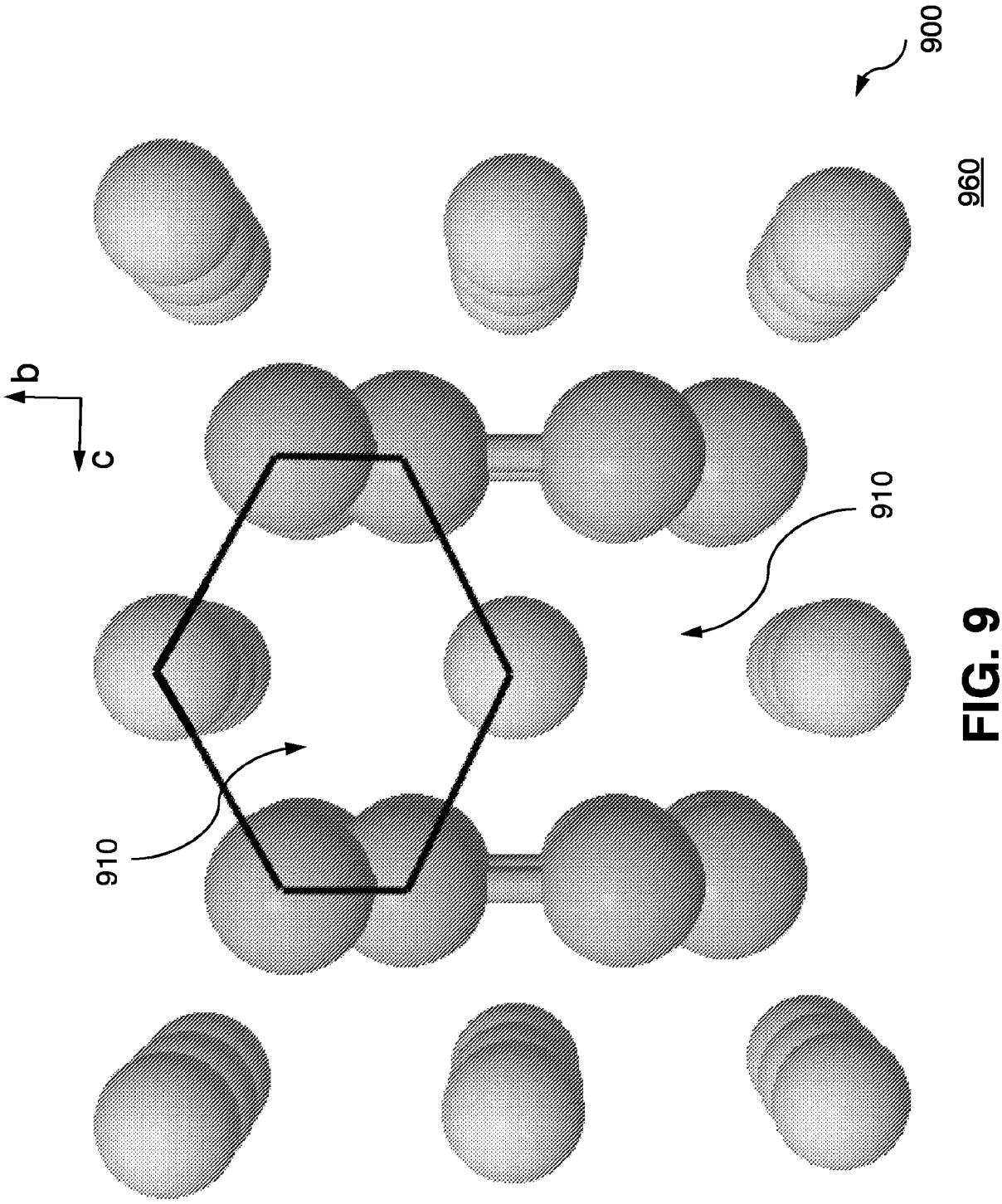


FIG. 9

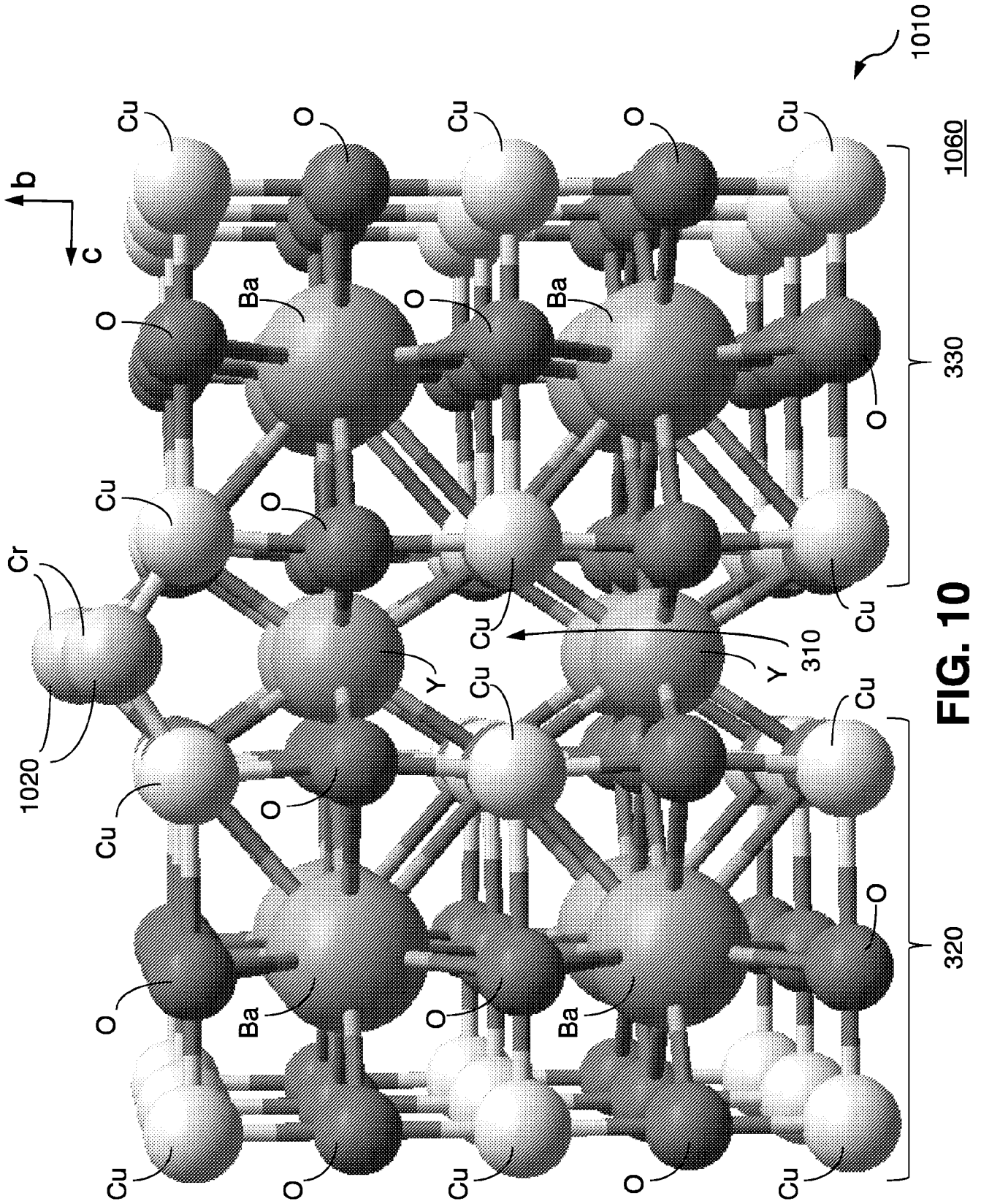


FIG. 10

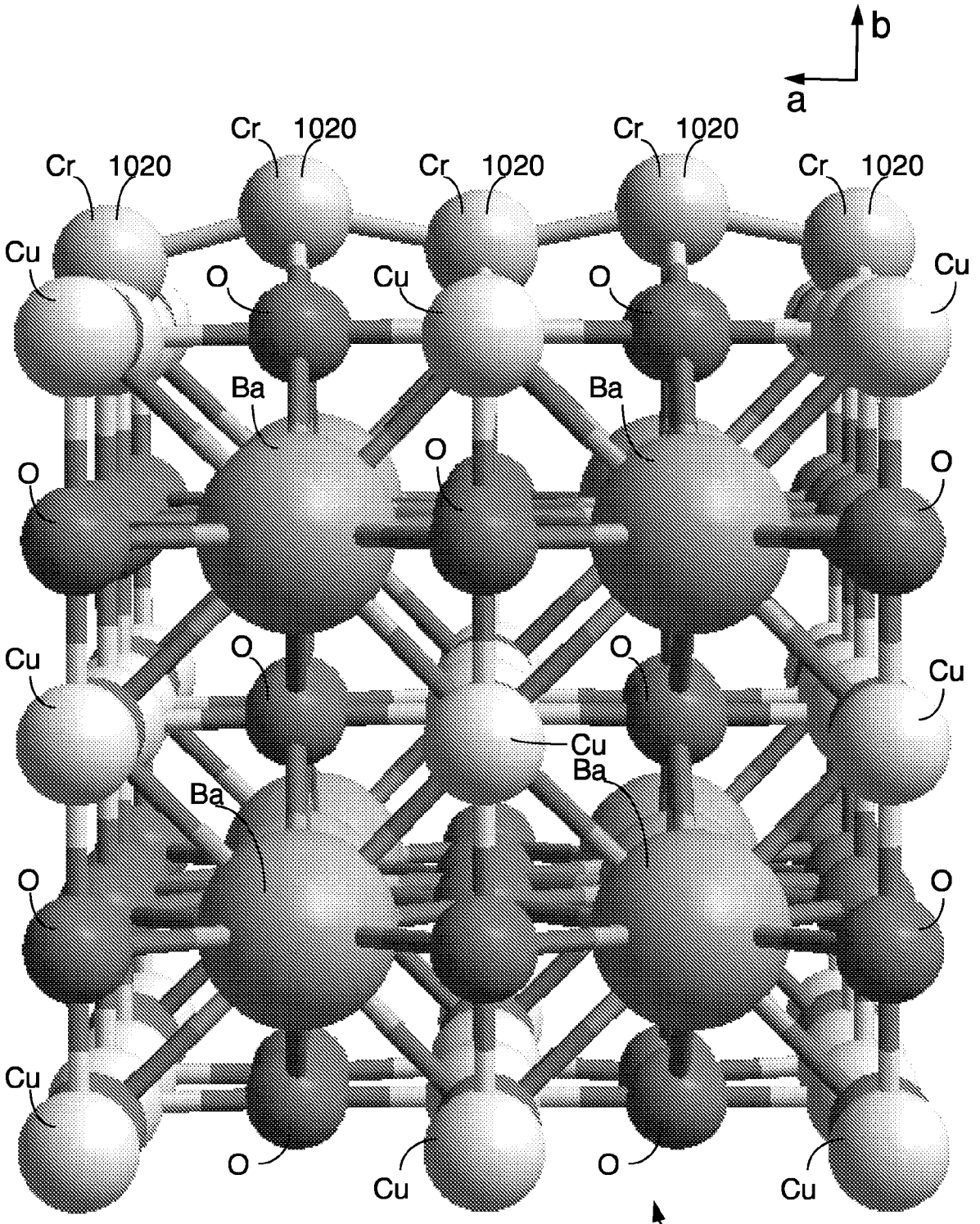


FIG. 11

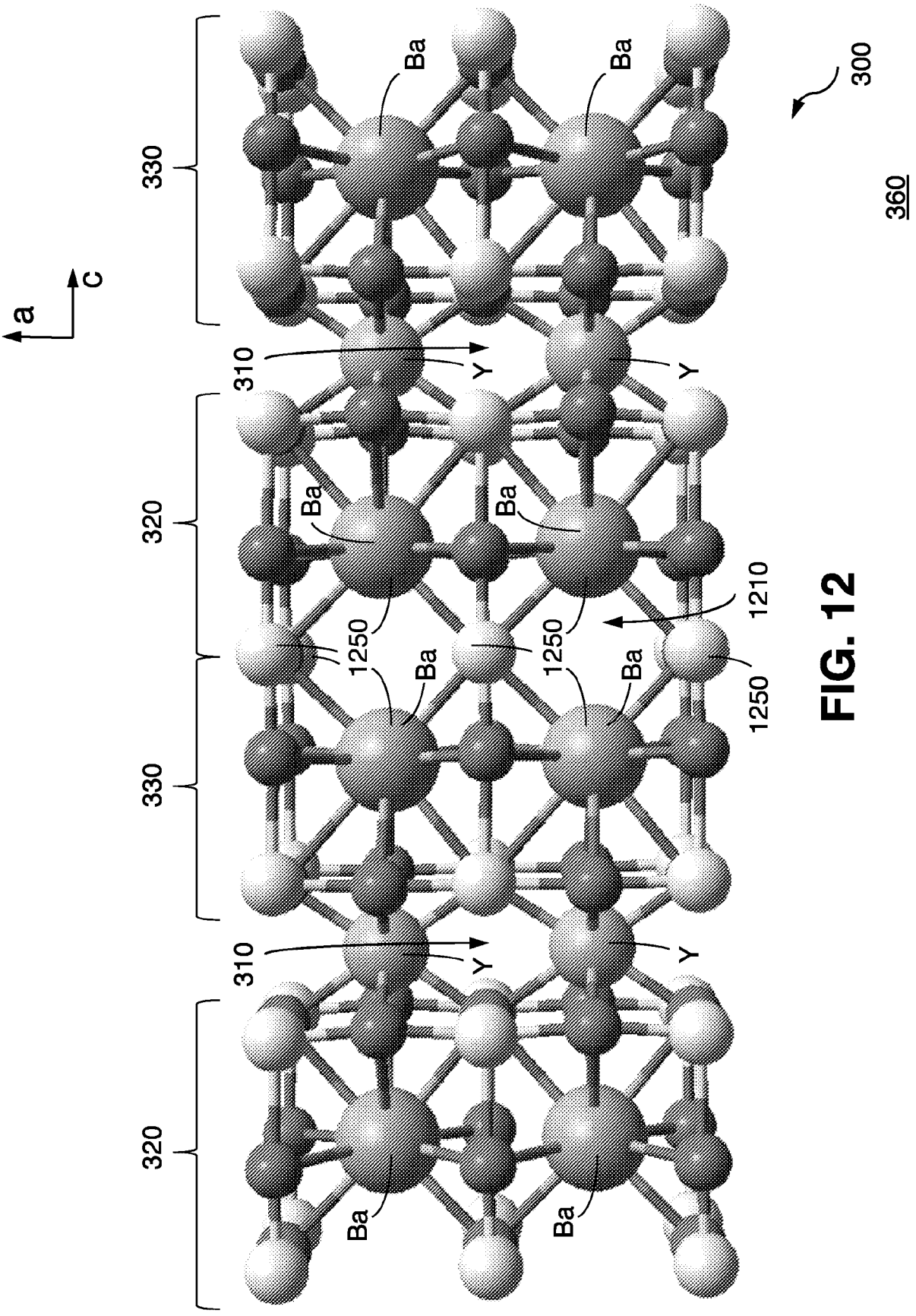

a
c
330
320
330
320
310
310
Y
Y
Y
Y
Ba
Ba
Ba
Ba
Ba
Ba
Ba
Ba
1250
1250
1250
1210
300
360

FIG. 12

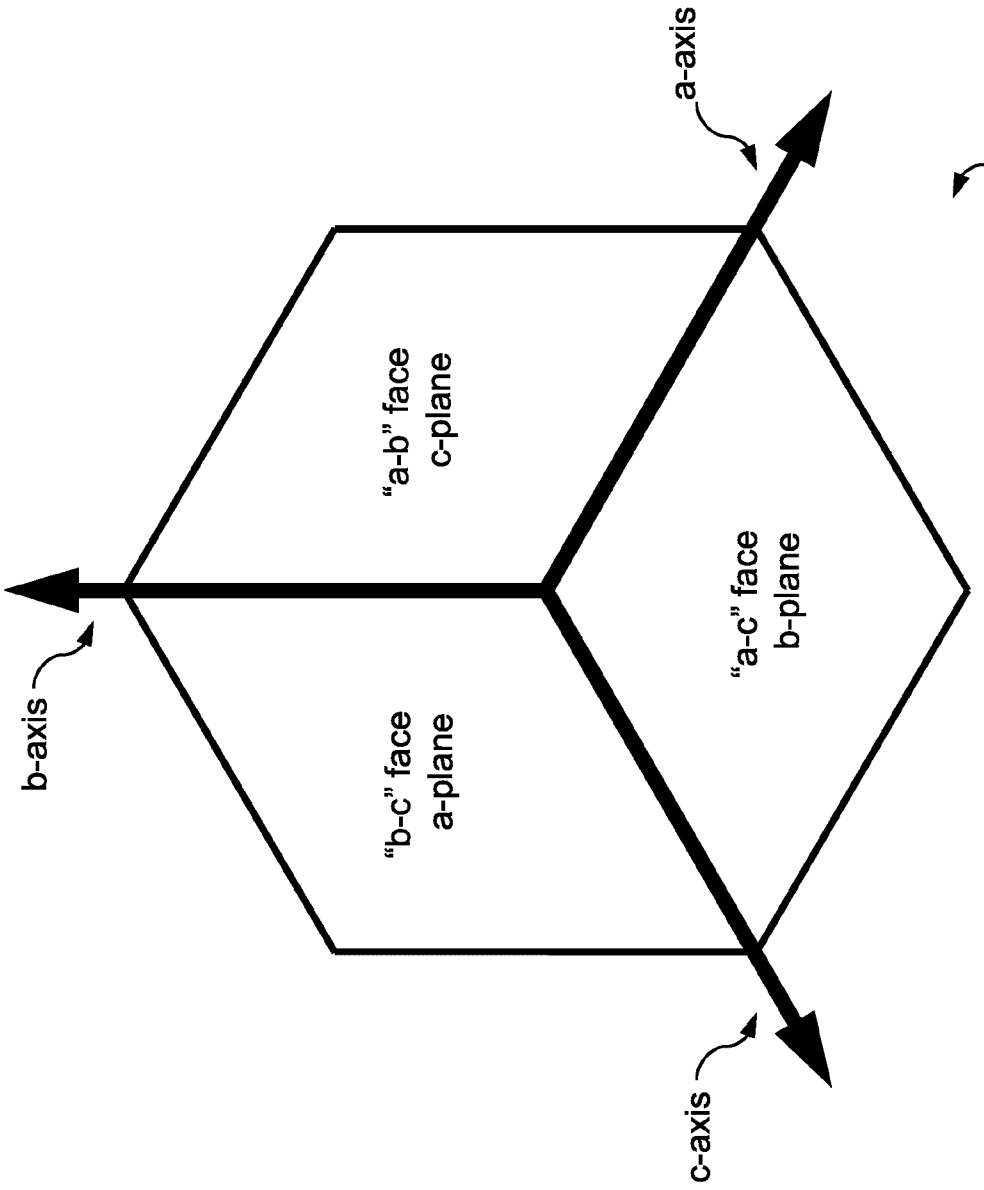

a-axis
1300
"a-b" face
c-plane
"a-c" face
b-plane
b-axis
"b-c" face
a-plane
c-axis

FIG. 13

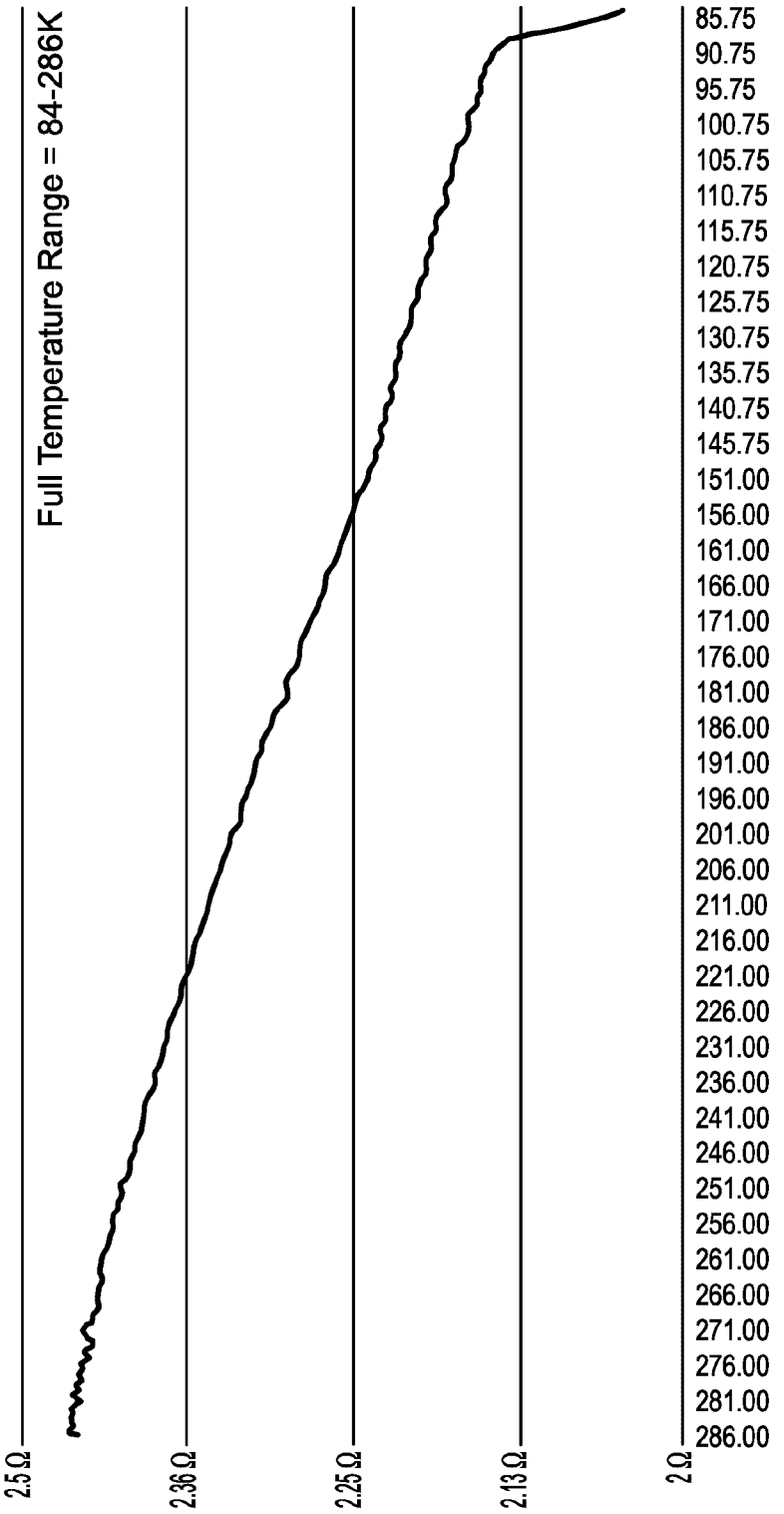

Full Temperature Range = 84-286K
2.5 Ω
2.36 Ω
2.25 Ω
2.13 Ω
2 Ω
85.75
90.75
95.75
100.75
105.75
110.75
115.75
120.75
125.75
130.75
135.75
140.75
145.75
151.00
156.00
161.00
166.00
171.00
176.00
181.00
186.00
191.00
196.00
201.00
206.00
211.00
216.00
221.00
226.00
231.00
236.00
241.00
246.00
251.00
256.00
261.00
266.00
271.00
276.00
281.00
286.00
1400

Fig. 14A

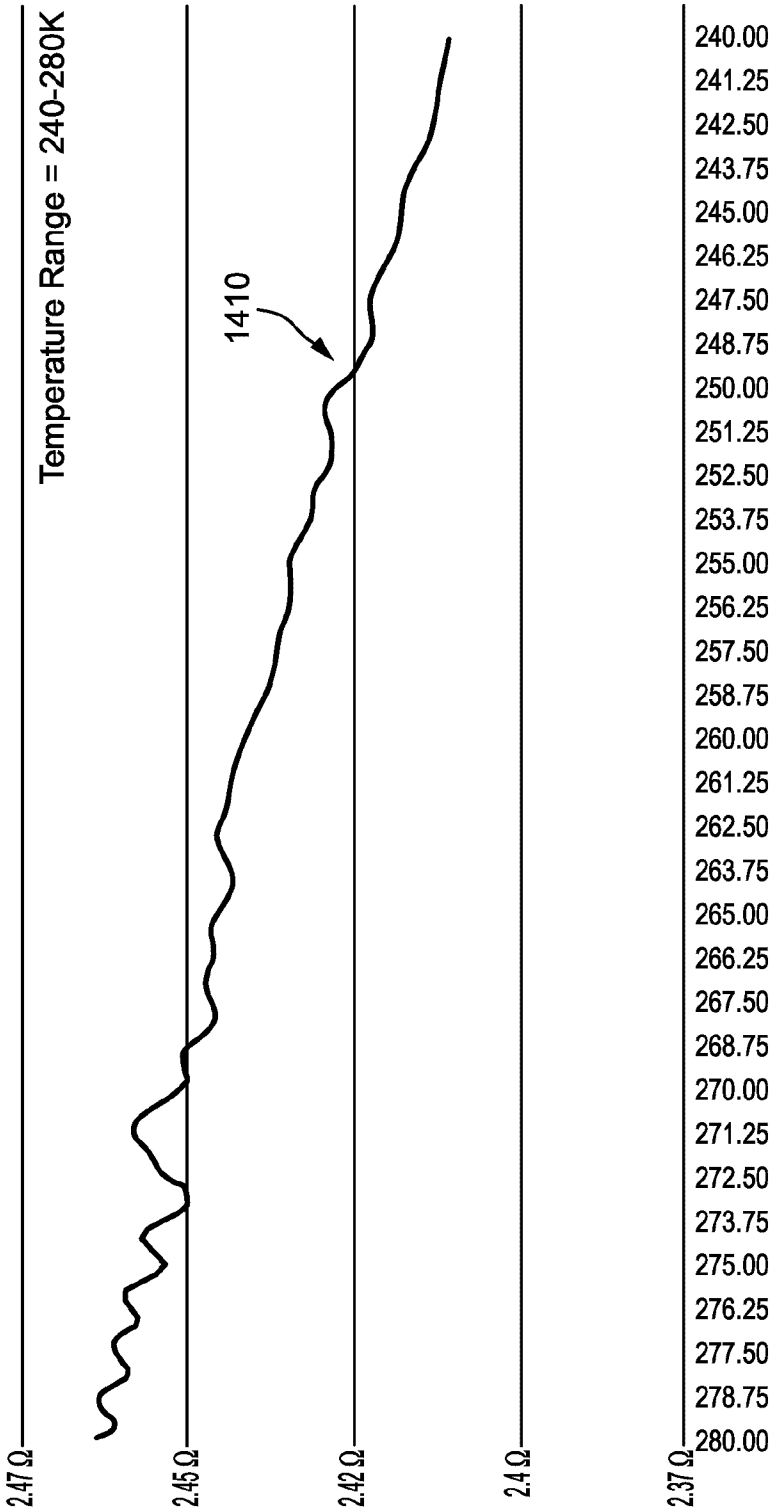

Temperature Range = 240-280K
1410
2.47 Ω
2.45 Ω
2.42 Ω
2.4 Ω
2.37 Ω
240.00
241.25
242.50
243.75
245.00
246.25
247.50
248.75
250.00
251.25
252.50
253.75
255.00
256.25
257.50
258.75
260.00
261.25
262.50
263.75
265.00
266.25
267.50
268.75
270.00
271.25
272.50
273.75
275.00
276.25
277.50
278.75
280.00

Fig. 14B

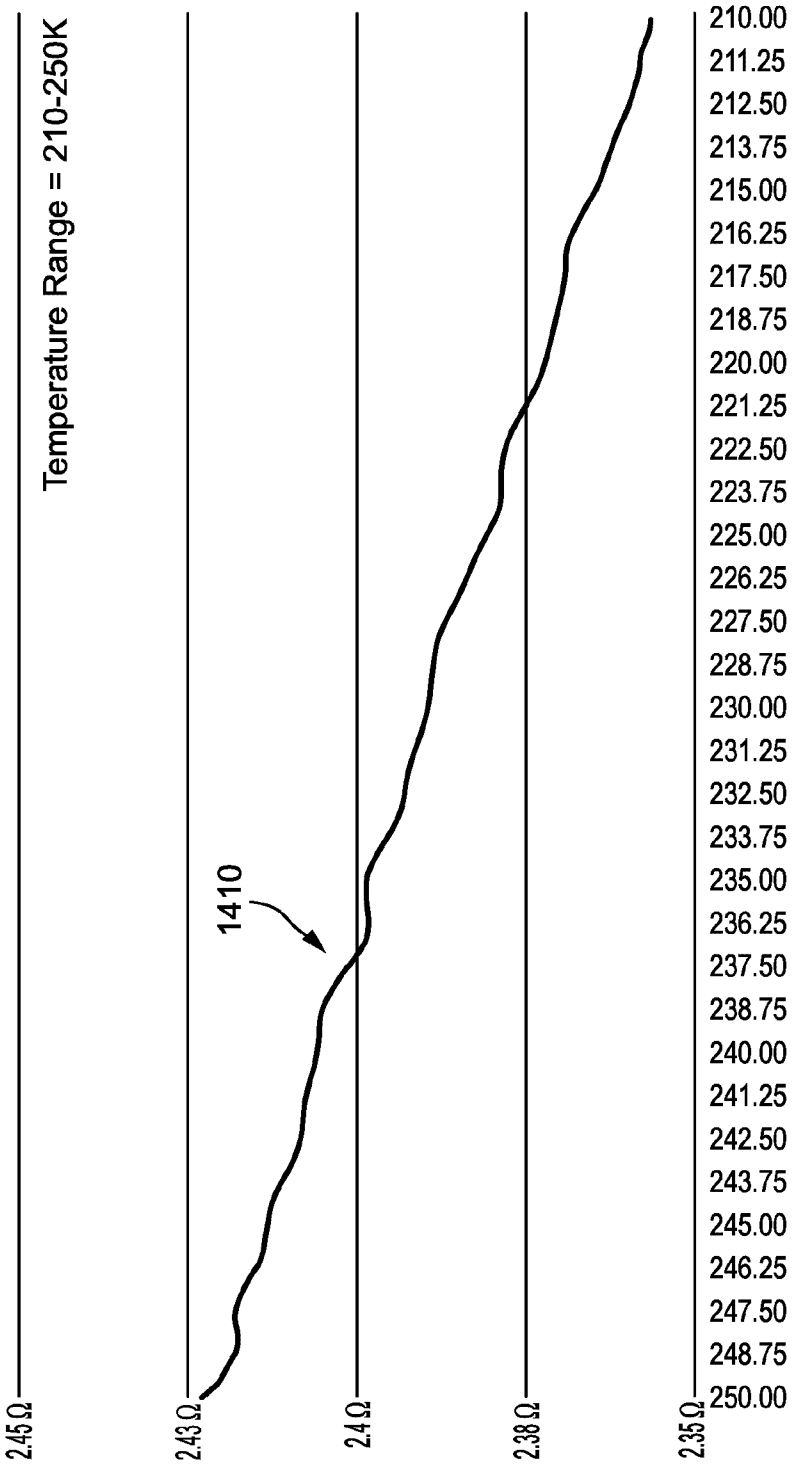

Temperature Range = 210-250K
1410
2.45 Ω
2.43 Ω
2.4 Ω
2.38 Ω
2.35 Ω
210.00
211.25
212.50
213.75
215.00
216.25
217.50
218.75
220.00
221.25
222.50
223.75
225.00
226.25
227.50
228.75
230.00
231.25
232.50
233.75
235.00
236.25
237.50
238.75
240.00
241.25
242.50
243.75
245.00
246.25
247.50
248.75
250.00

Fig. 14C

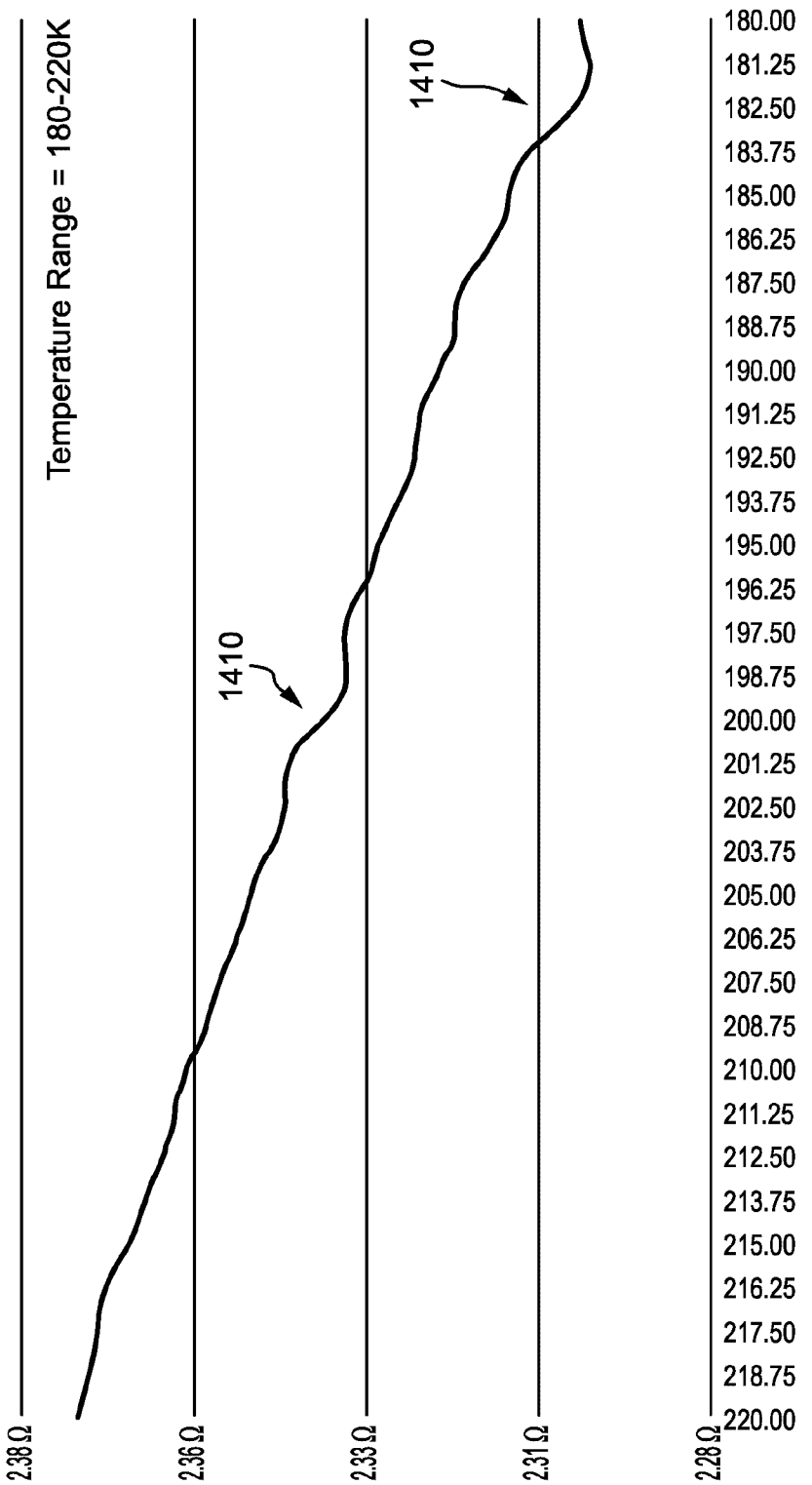

Temperature Range = 180-220K
1410
1410
2.38 Ω
2.36 Ω
2.33 Ω
2.31 Ω
2.28 Ω
180.00
181.25
182.50
183.75
185.00
186.25
187.50
188.75
190.00
191.25
192.50
193.75
195.00
196.25
197.50
198.75
200.00
201.25
202.50
203.75
205.00
206.25
207.50
208.75
210.00
211.25
212.50
213.75
215.00
216.25
217.50
218.75
220.00

Fig. 14D

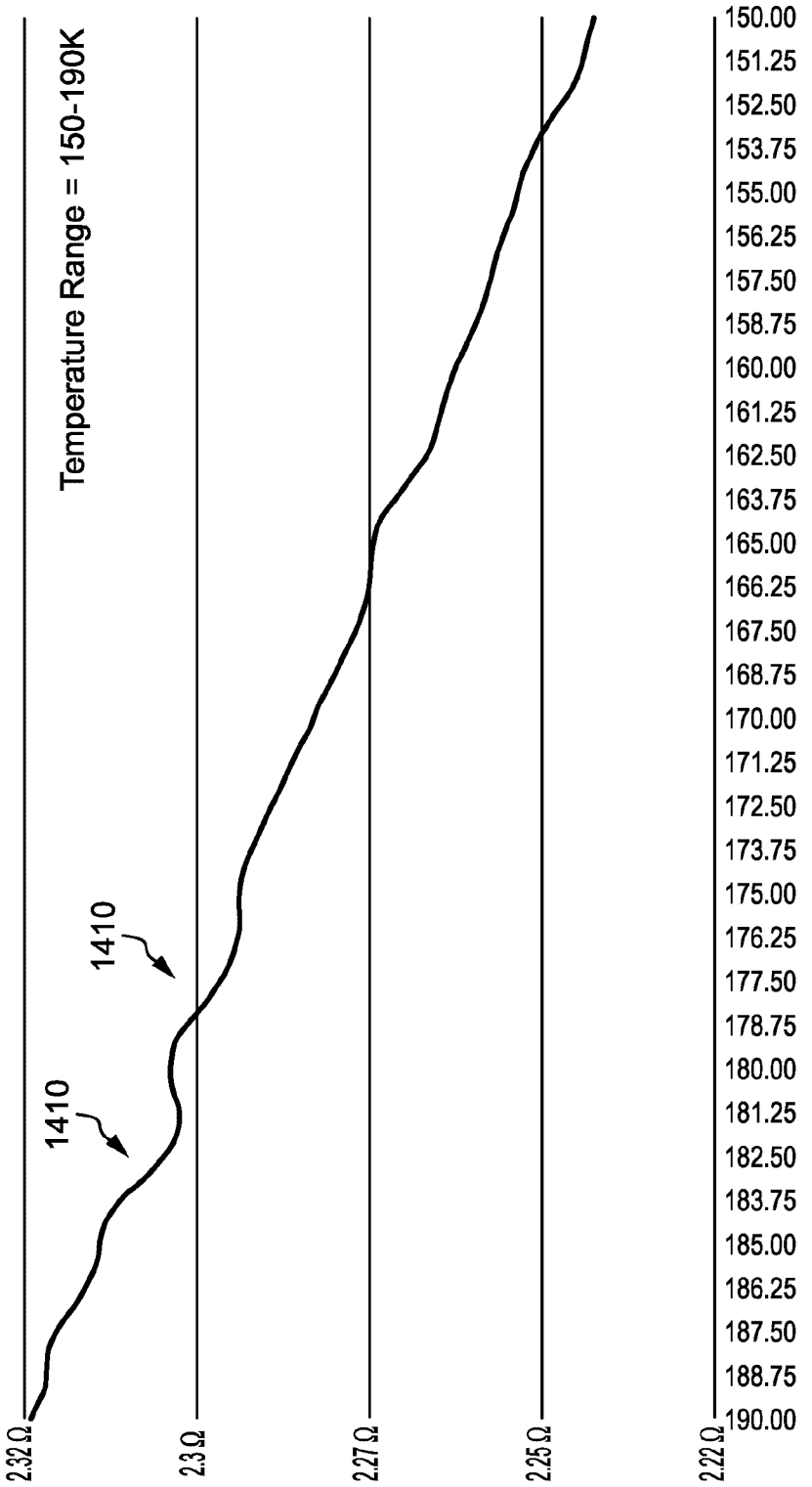

Temperature Range = 150-190K
1410
1410
2.32 Ω
2.3 Ω
2.27 Ω
2.25 Ω
2.22 Ω
150.00
151.25
152.50
153.75
155.00
156.25
157.50
158.75
160.00
161.25
162.50
163.75
165.00
166.25
167.50
168.75
170.00
171.25
172.50
173.75
175.00
176.25
177.50
178.75
180.00
181.25
182.50
183.75
185.00
186.25
187.50
188.75
190.00

Fig. 14E

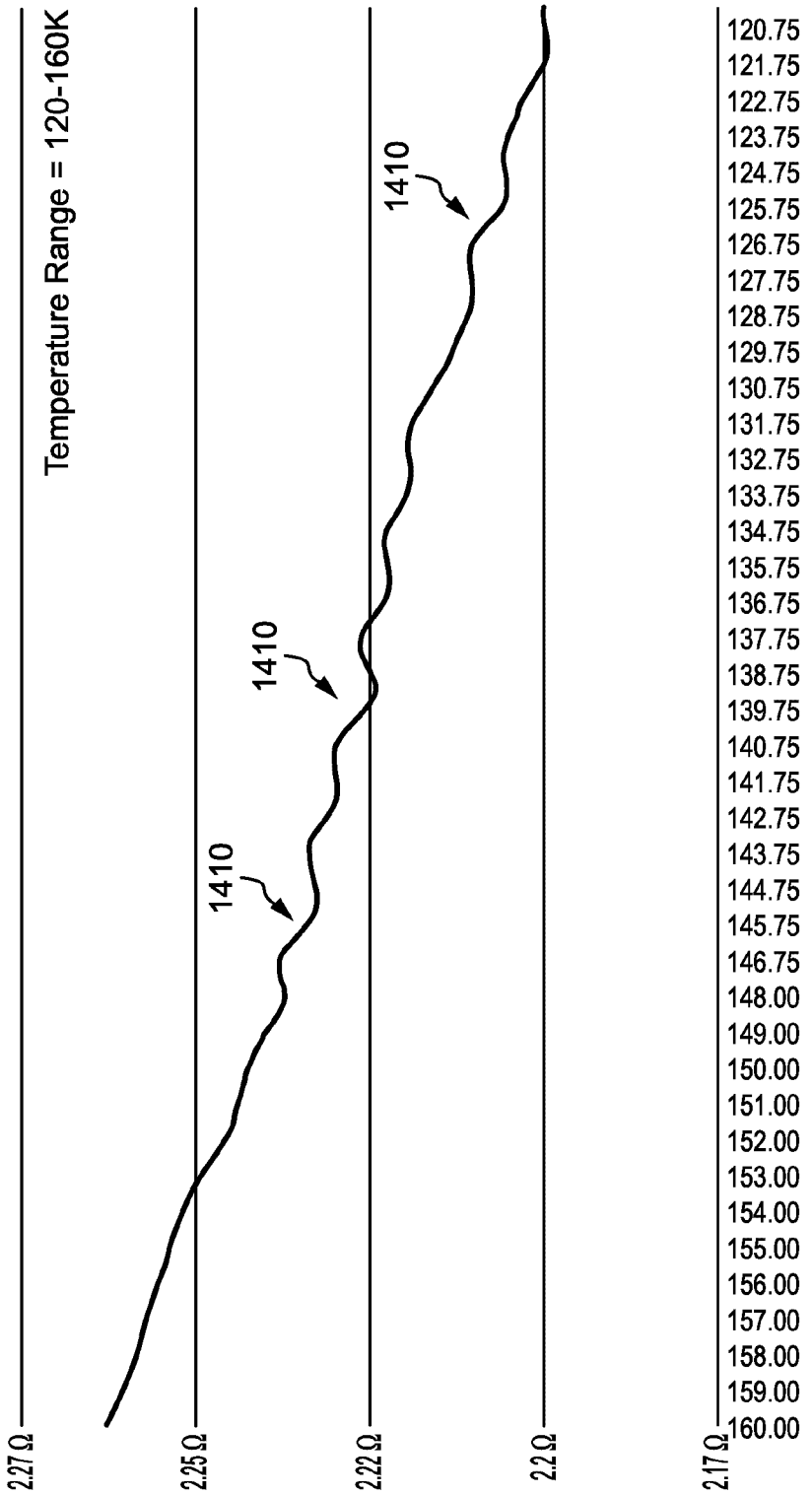

Temperature Range = 120-160K
1410
1410
1410
2.27 Ω
2.25 Ω
2.22 Ω
2.2 Ω
2.17 Ω
120.75
121.75
122.75
123.75
124.75
125.75
126.75
127.75
128.75
129.75
130.75
131.75
132.75
133.75
134.75
135.75
136.75
137.75
138.75
139.75
140.75
141.75
142.75
143.75
144.75
145.75
146.75
148.00
149.00
150.00
151.00
152.00
153.00
154.00
155.00
156.00
157.00
158.00
159.00
160.00

Fig. 14F

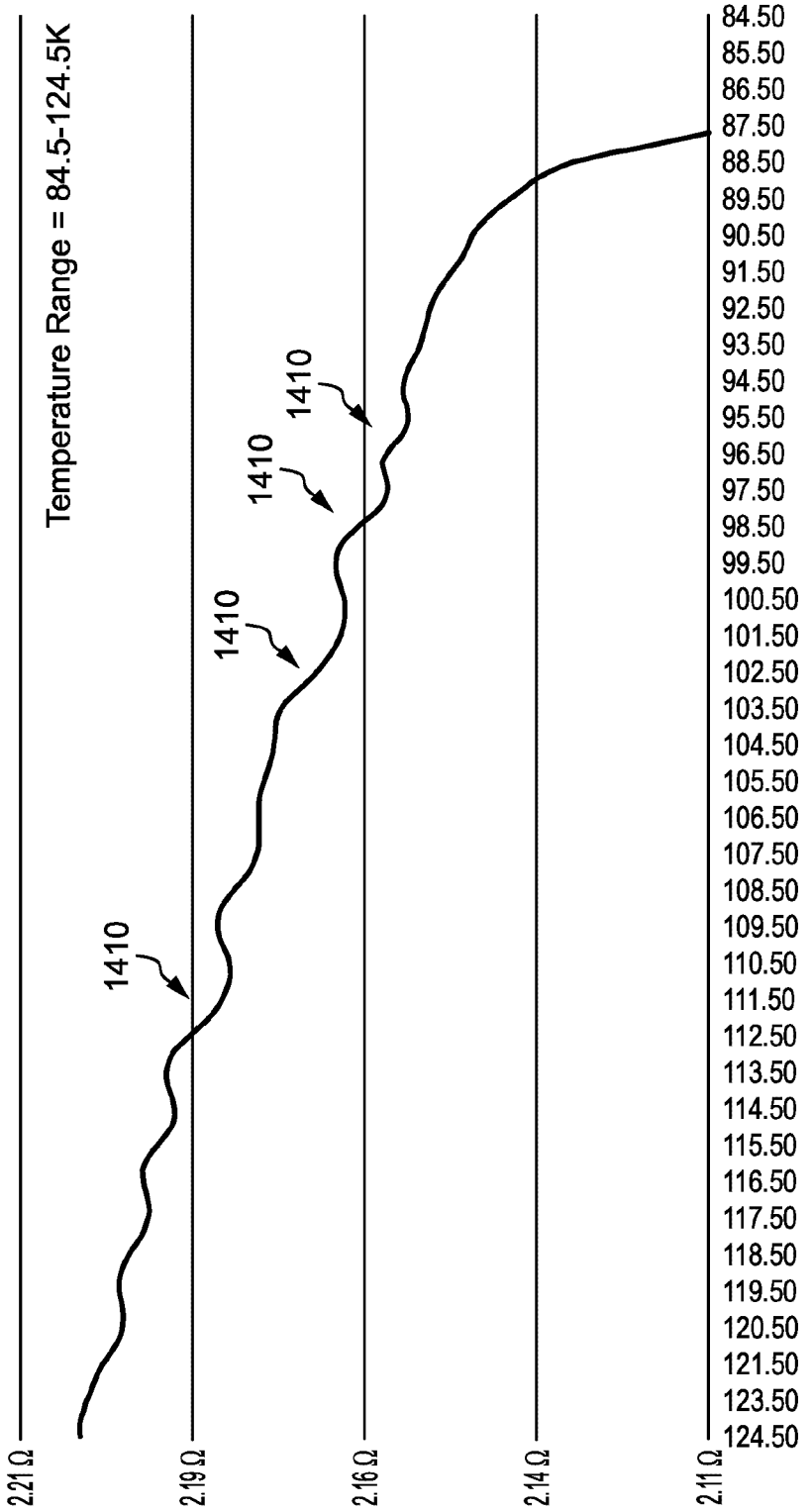

Temperature Range = 84.5-124.5K
1410
1410
1410
1410
2.21 Ω
2.19 Ω
2.16 Ω
2.14 Ω
2.11 Ω
84.50
85.50
86.50
87.50
88.50
89.50
90.50
91.50
92.50
93.50
94.50
95.50
96.50
97.50
98.50
99.50
100.50
101.50
102.50
103.50
104.50
105.50
106.50
107.50
108.50
109.50
110.50
111.50
112.50
113.50
114.50
115.50
116.50
117.50
118.50
119.50
120.50
121.50
123.50
124.50

Fig. 14G

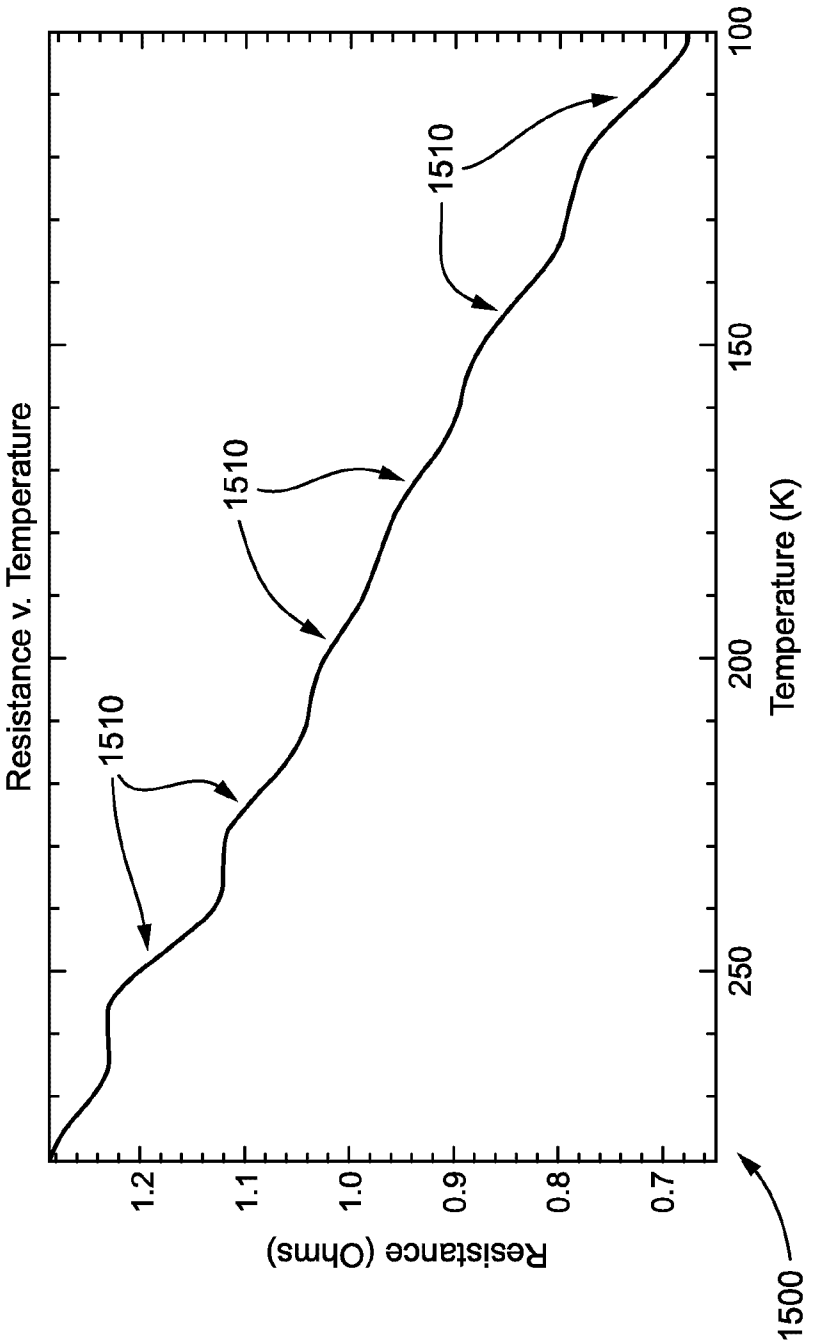

Resistance v. Temperature
Resistance (Ohms)
1.2
1.1
1.0
0.9
0.8
0.7
Temperature (K)
100
150
200
250
1510
1510
1510
1500

FIG. 15

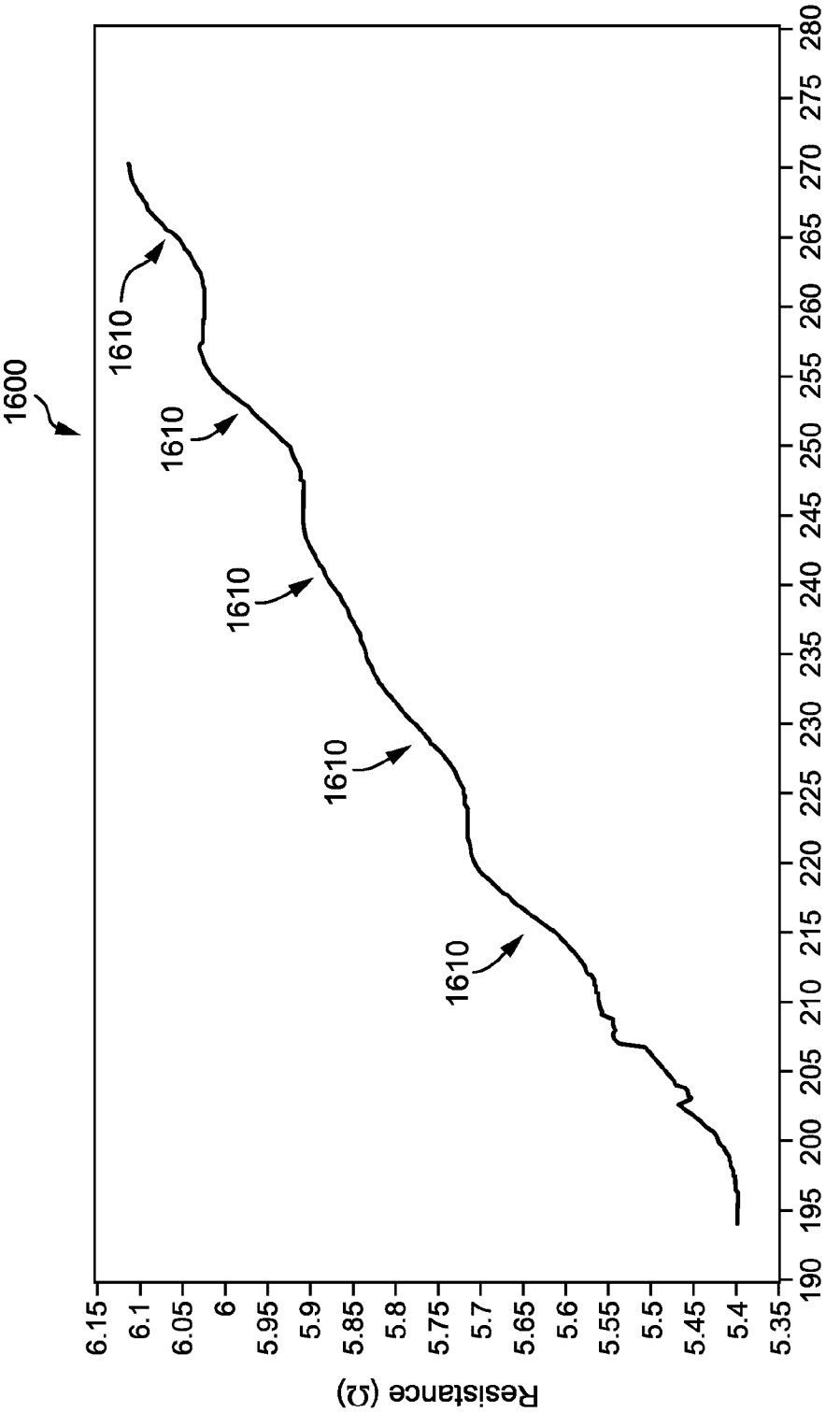

1600
1610
1610
1610
1610
1610
Resistance (Ω)
6.15
6.1
6.05
6
5.95
5.9
5.85
5.8
5.75
5.7
5.65
5.6
5.55
5.5
5.45
5.4
5.35
190 195 200 205 210 215 220 225 230 235 240 245 250 255 260 265 270 275 280
Temperature (K)

FIG. 16

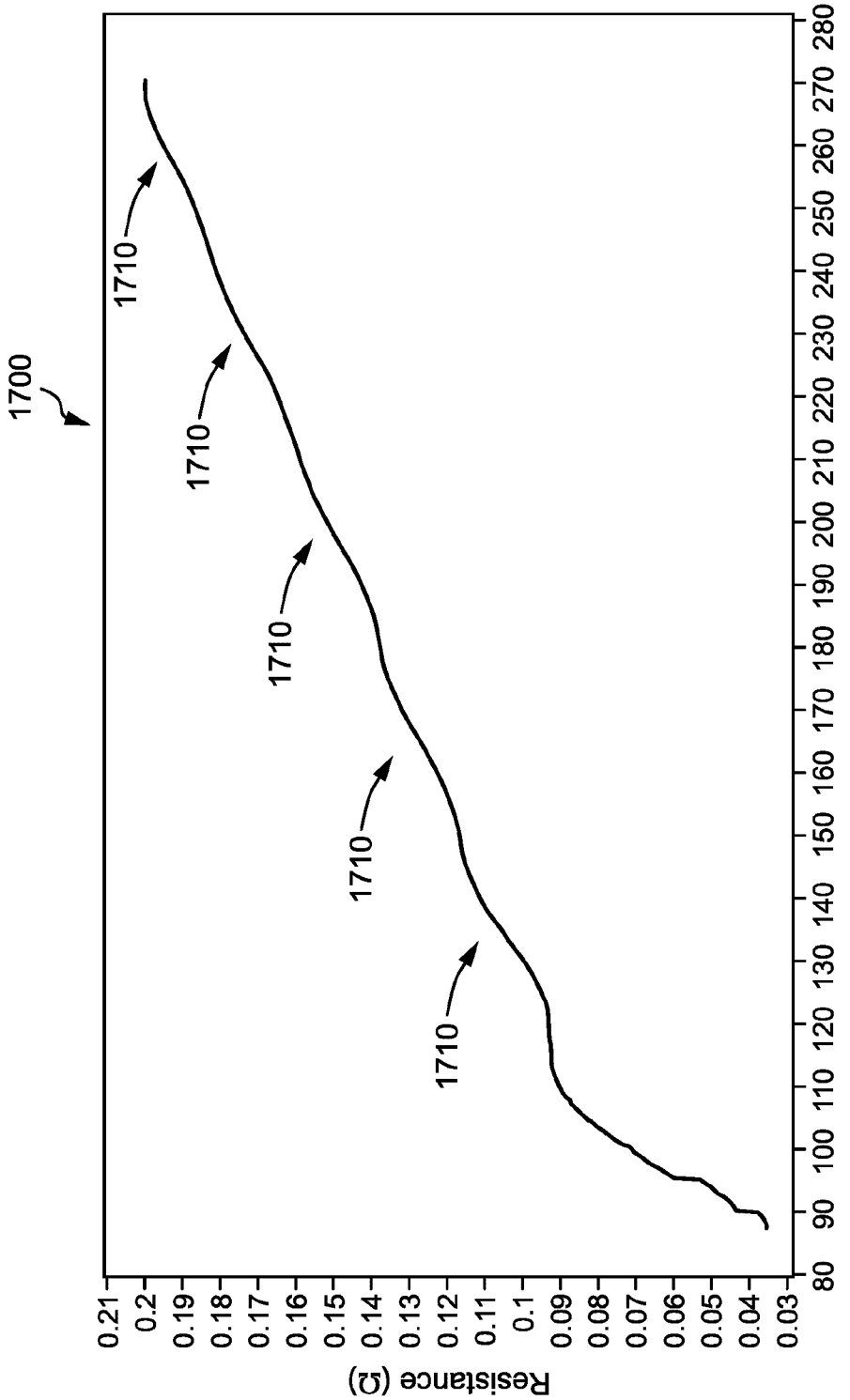

1700
1710
1710
1710
1710
1710
Resistance (Ω)
0.21
0.2
0.19
0.18
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
Temperature (K)
80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250 260 270 280

FIG. 17

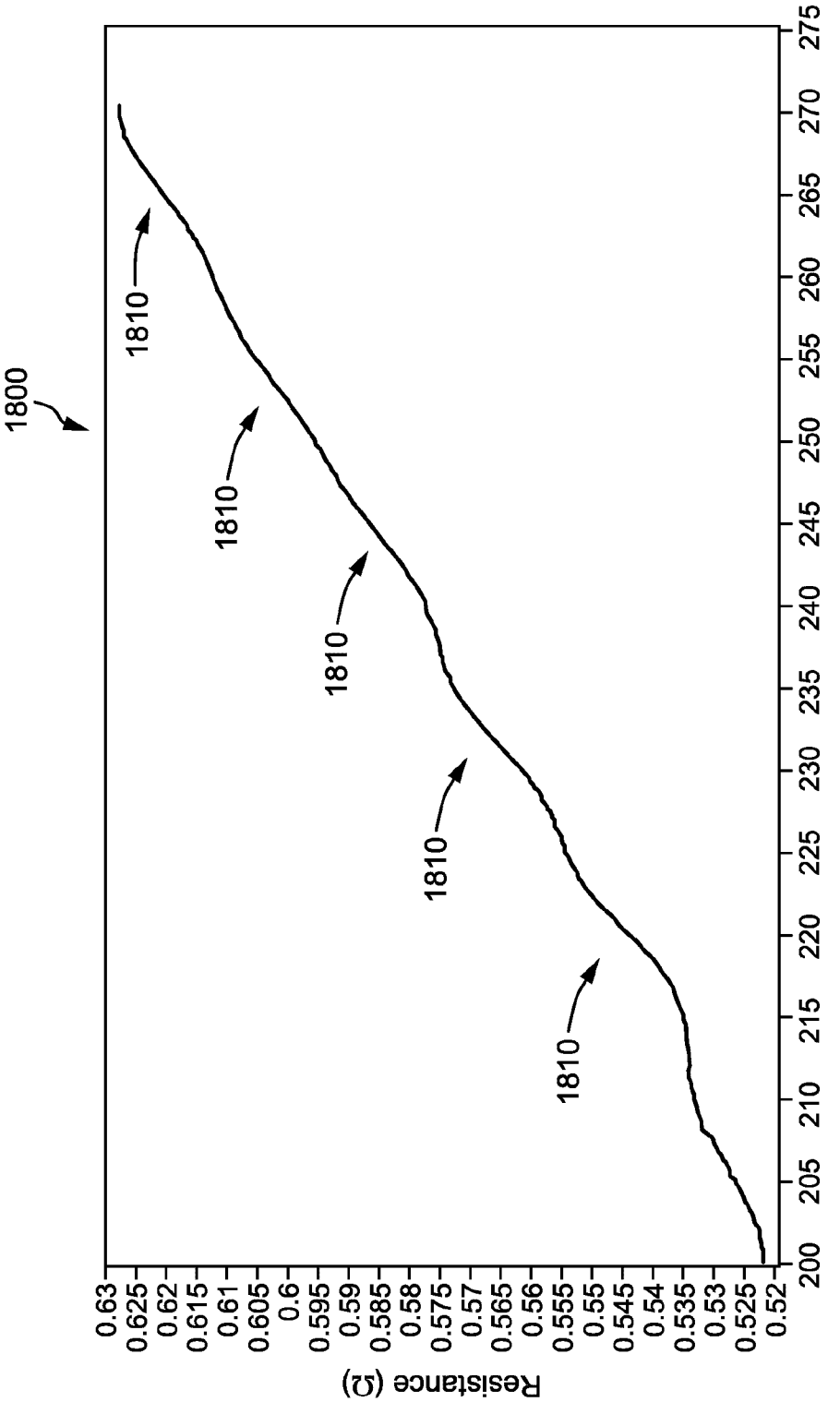

1800
1810
1810
1810
1810
1810
Resistance (Ω)
0.63
0.625
0.62
0.615
0.61
0.605
0.6
0.595
0.59
0.585
0.58
0.575
0.57
0.565
0.56
0.555
0.55
0.545
0.54
0.535
0.53
0.525
0.52
Temperature (K)
200
205
210
215
220
225
230
235
240
245
250
255
260
265
270
275

FIG. 18

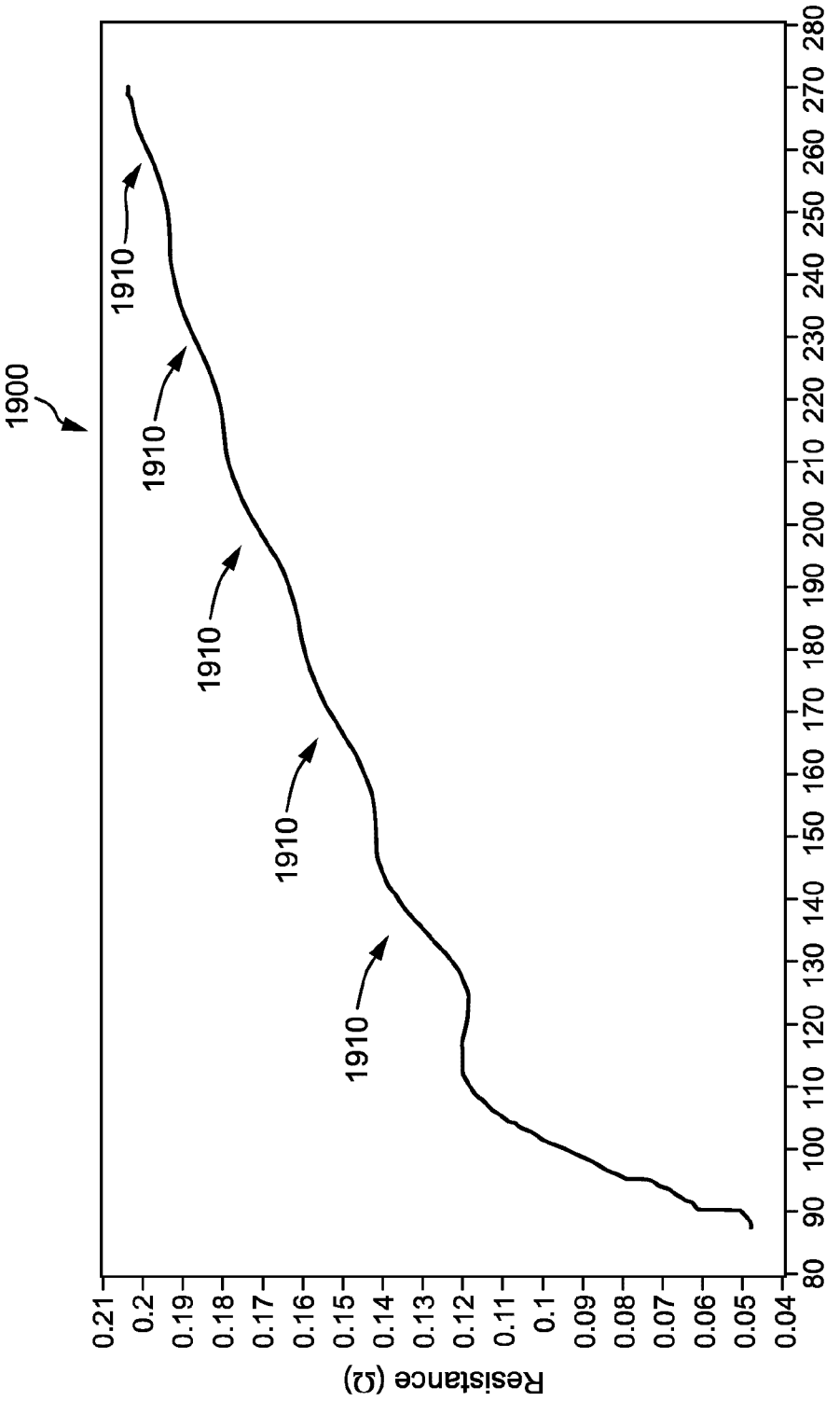

1900
1910
1910
1910
1910
1910
Resistance (Ω)
0.21
0.2
0.19
0.18
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
Temperature (K)
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
260
270
280

FIG. 19

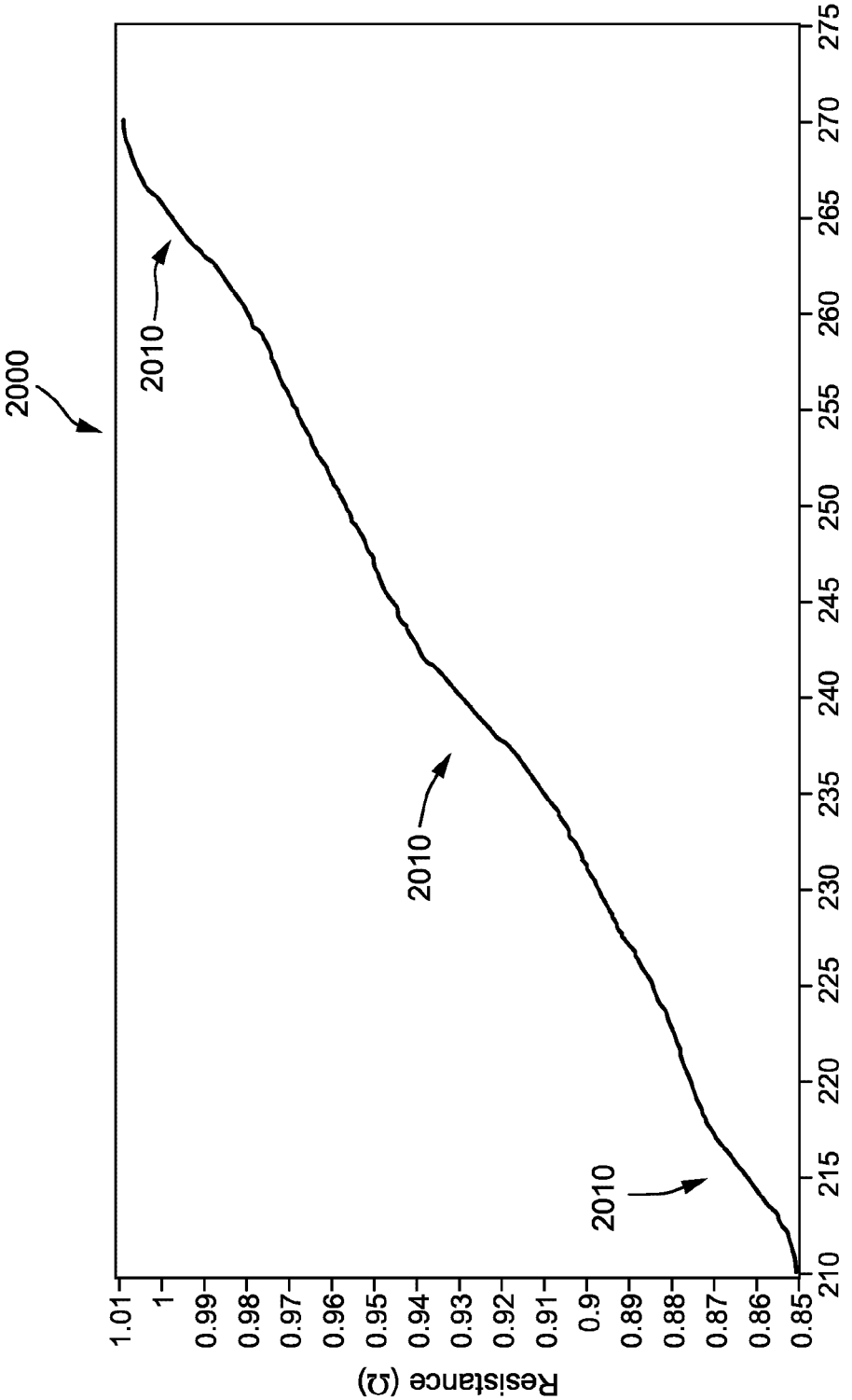

2000
2010
2010
2010
Resistance (Ω)
1.01
1
0.99
0.98
0.97
0.96
0.95
0.94
0.93
0.92
0.91
0.9
0.89
0.88
0.87
0.86
0.85
210
215
220
225
230
235
240
245
250
255
260
265
270
275
Temperature (K)

FIG. 20

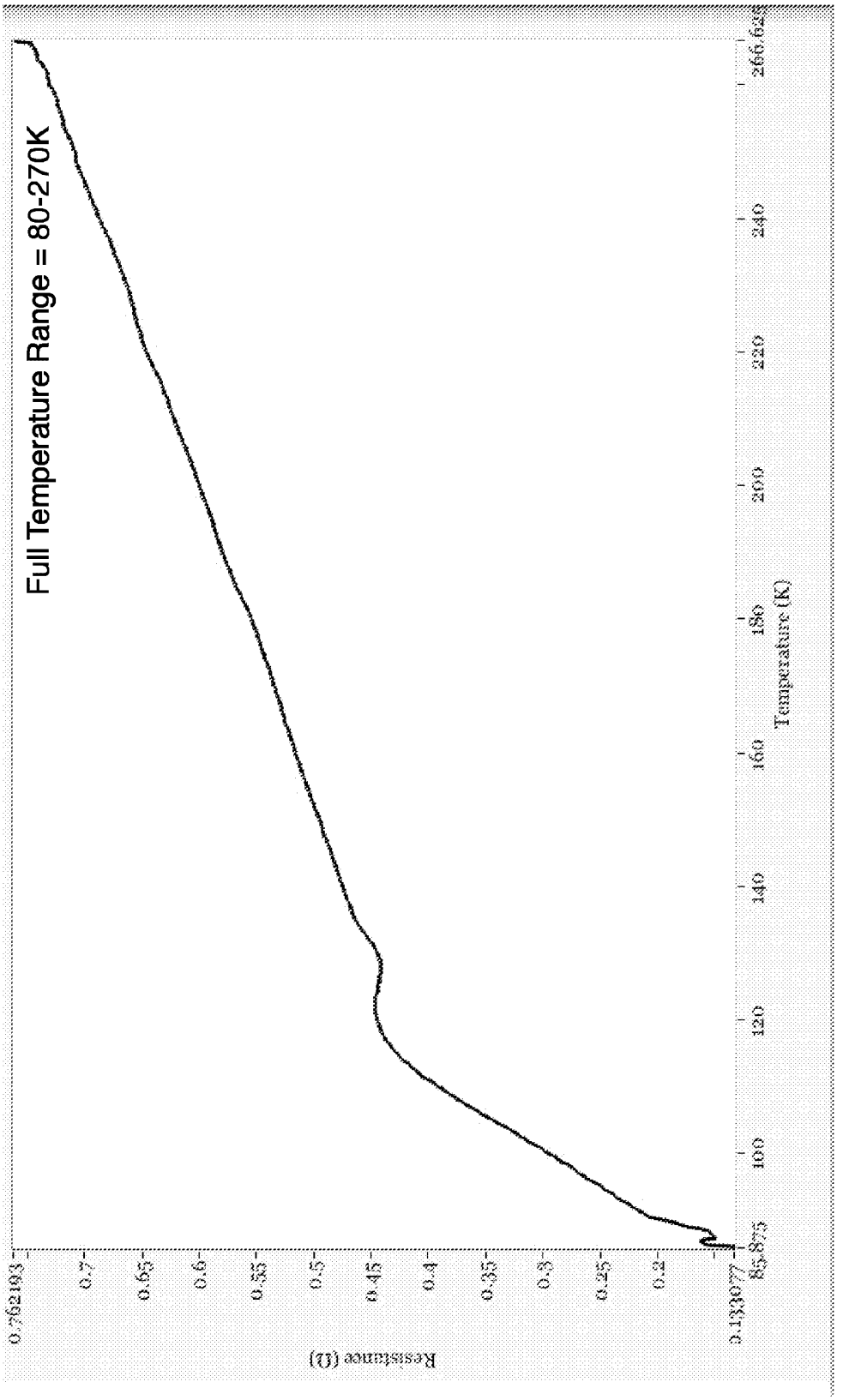

Full Temperature Range = 80-270K
Resistance (Ω)
0.762103
0.7
0.65
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.130077
85.875
100
120
140
160
180
200
220
240
266.628
Temperature (K)
2100

FIG. 21A

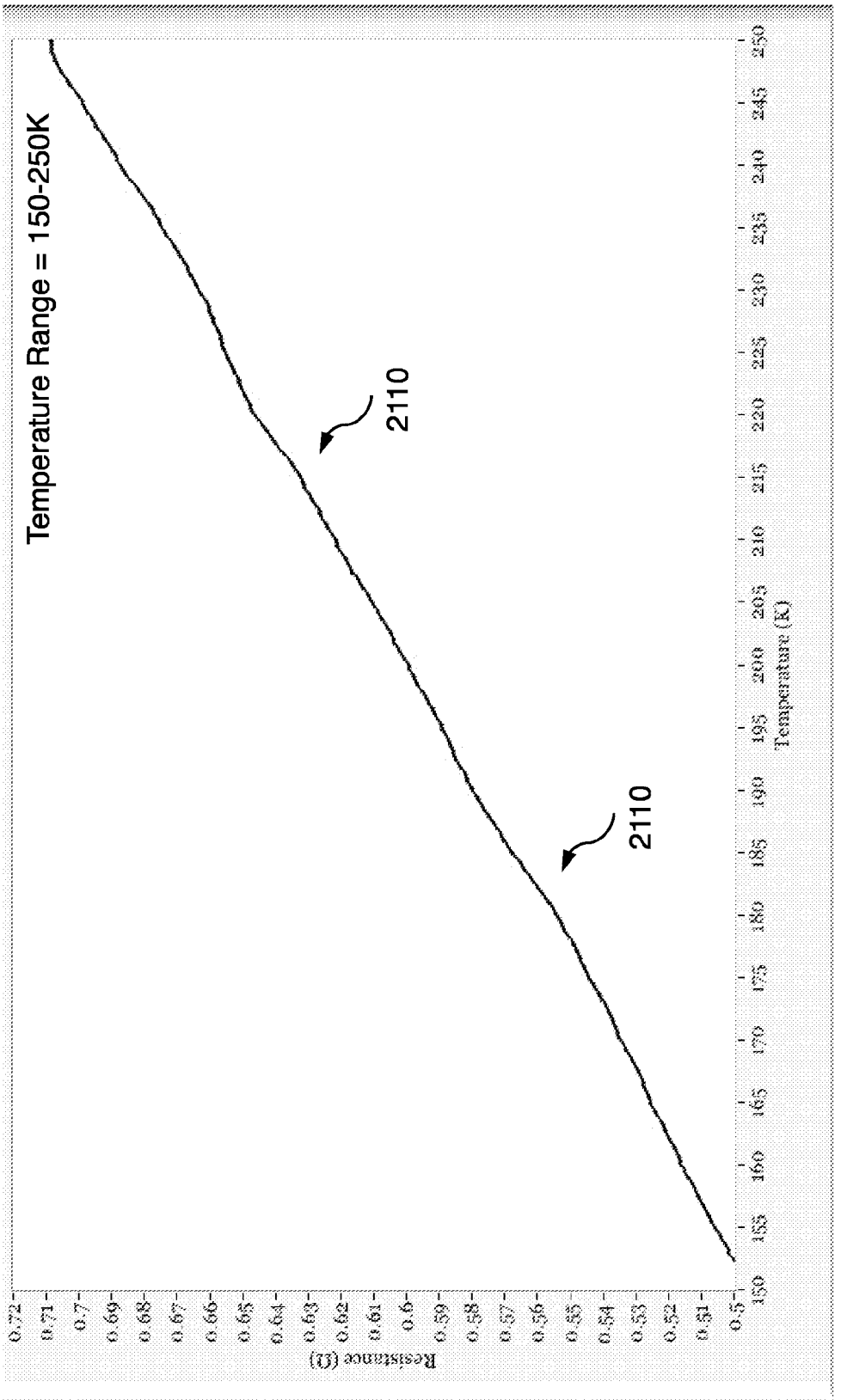

Temperature Range = 150-250K
2110
2110
Resistance (Ω)
Temperature (K)
0.72
0.71
0.7
0.69
0.68
0.67
0.66
0.65
0.64
0.63
0.62
0.61
0.6
0.59
0.58
0.57
0.56
0.55
0.54
0.53
0.52
0.51
150
155
160
165
170
175
180
185
190
195
200
205
210
215
220
225
230
235
240
245
250

FIG. 21B

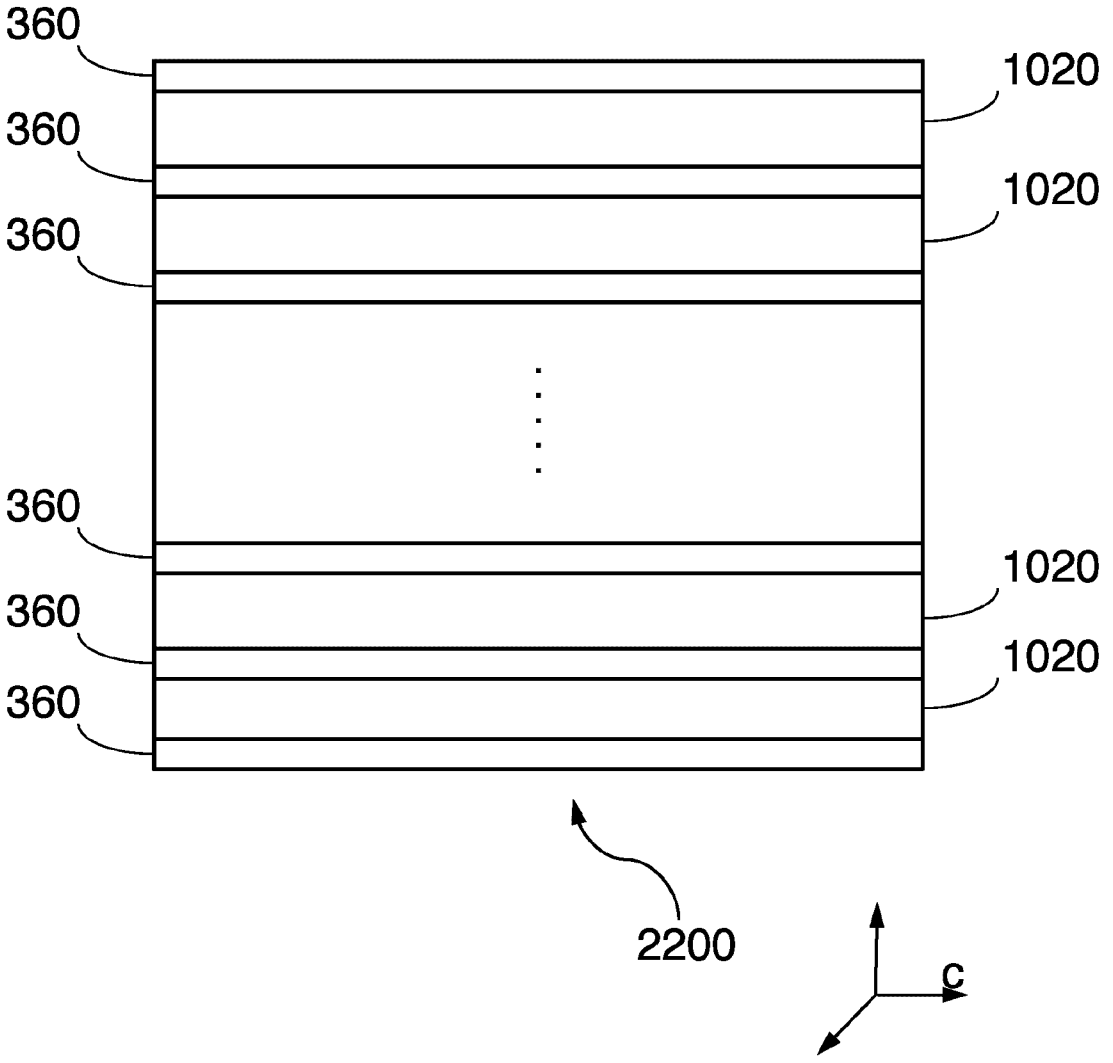


FIG. 22

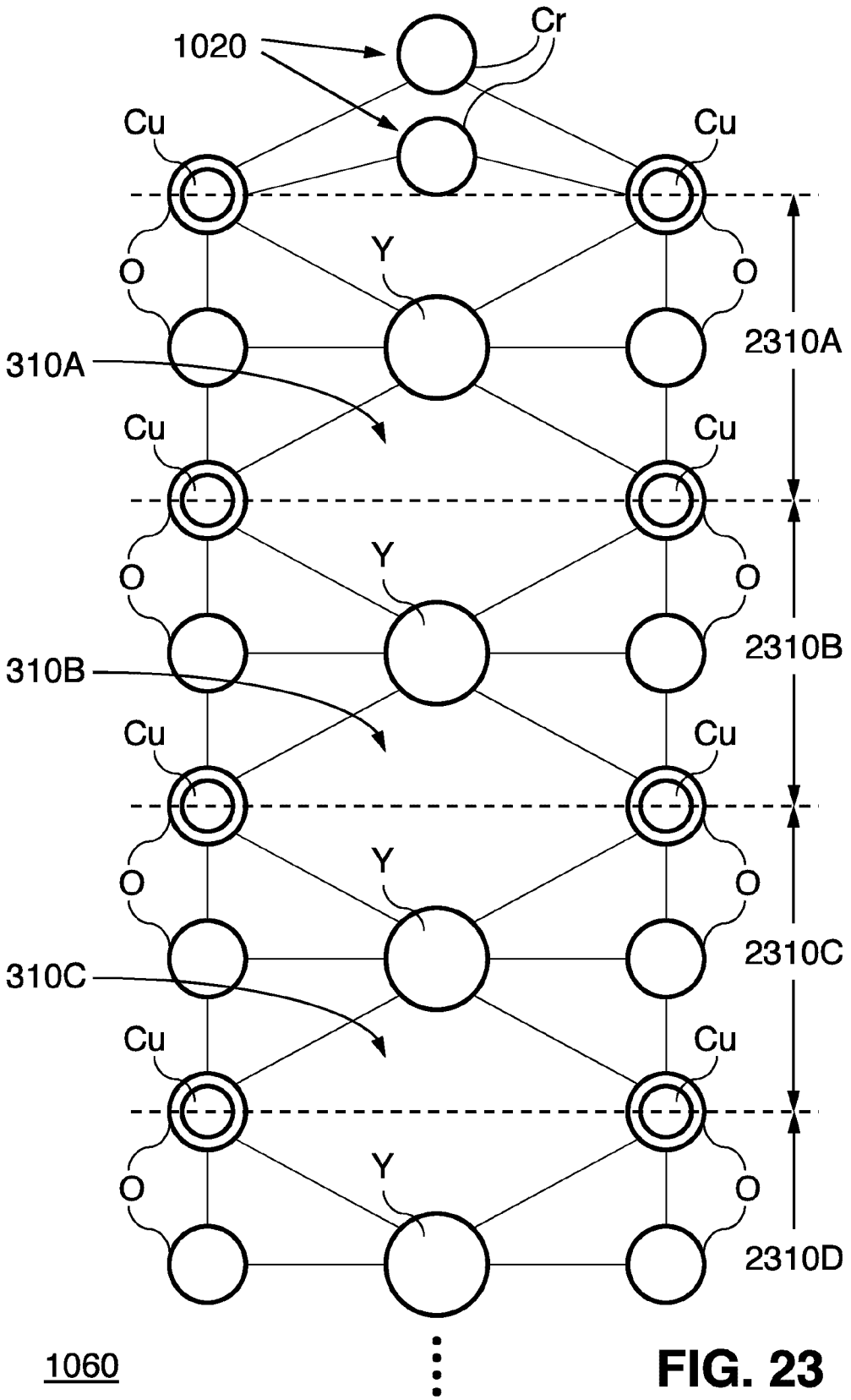

1020
Cr
Cu
Cu
O
Y
O
310A
2310A
Cu
Cu
O
Y
O
310B
2310B
Cu
Cu
O
Y
O
310C
2310C
Cu
Cu
O
Y
O
2310D
1060

FIG. 23

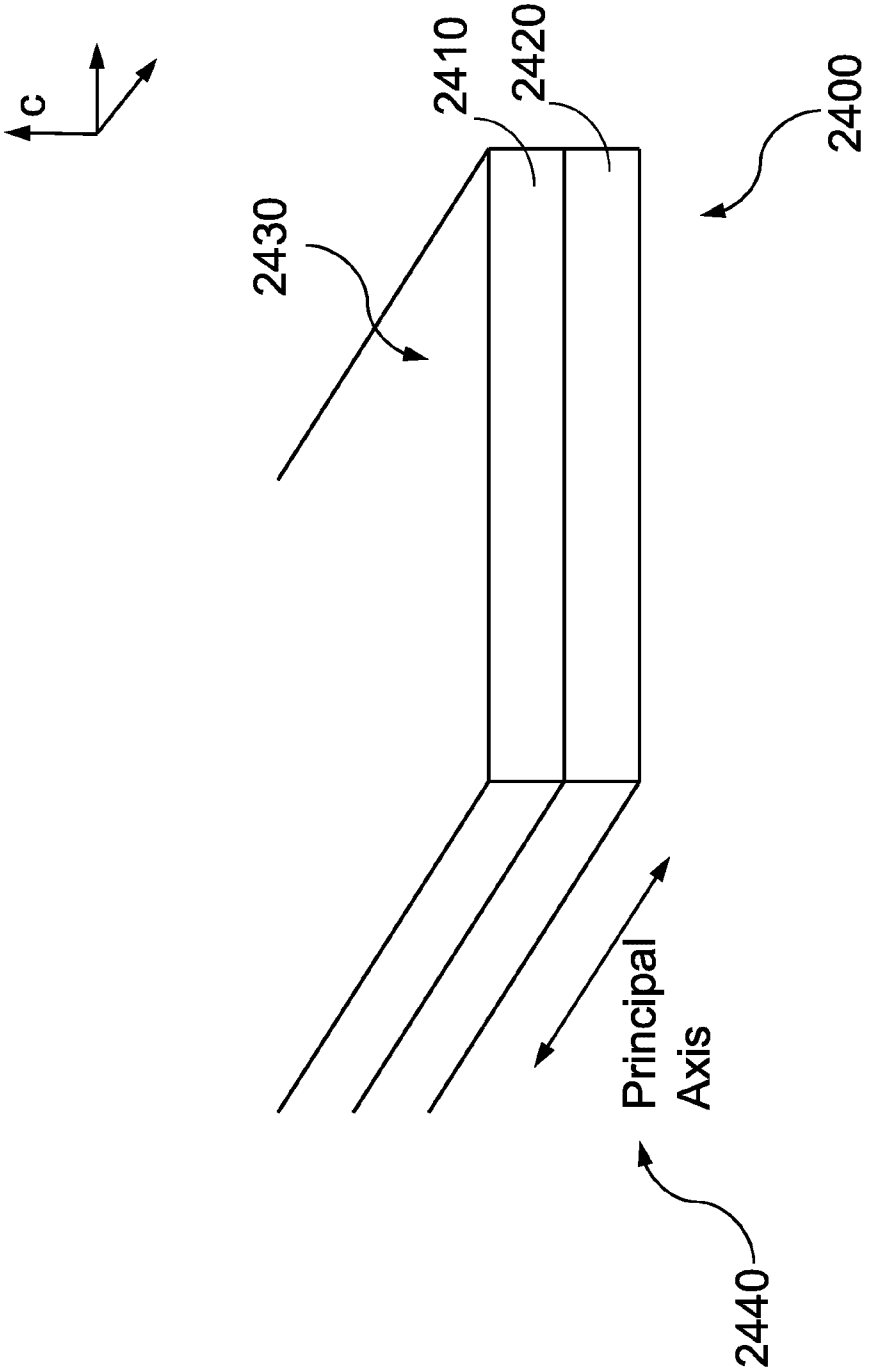


FIG. 24

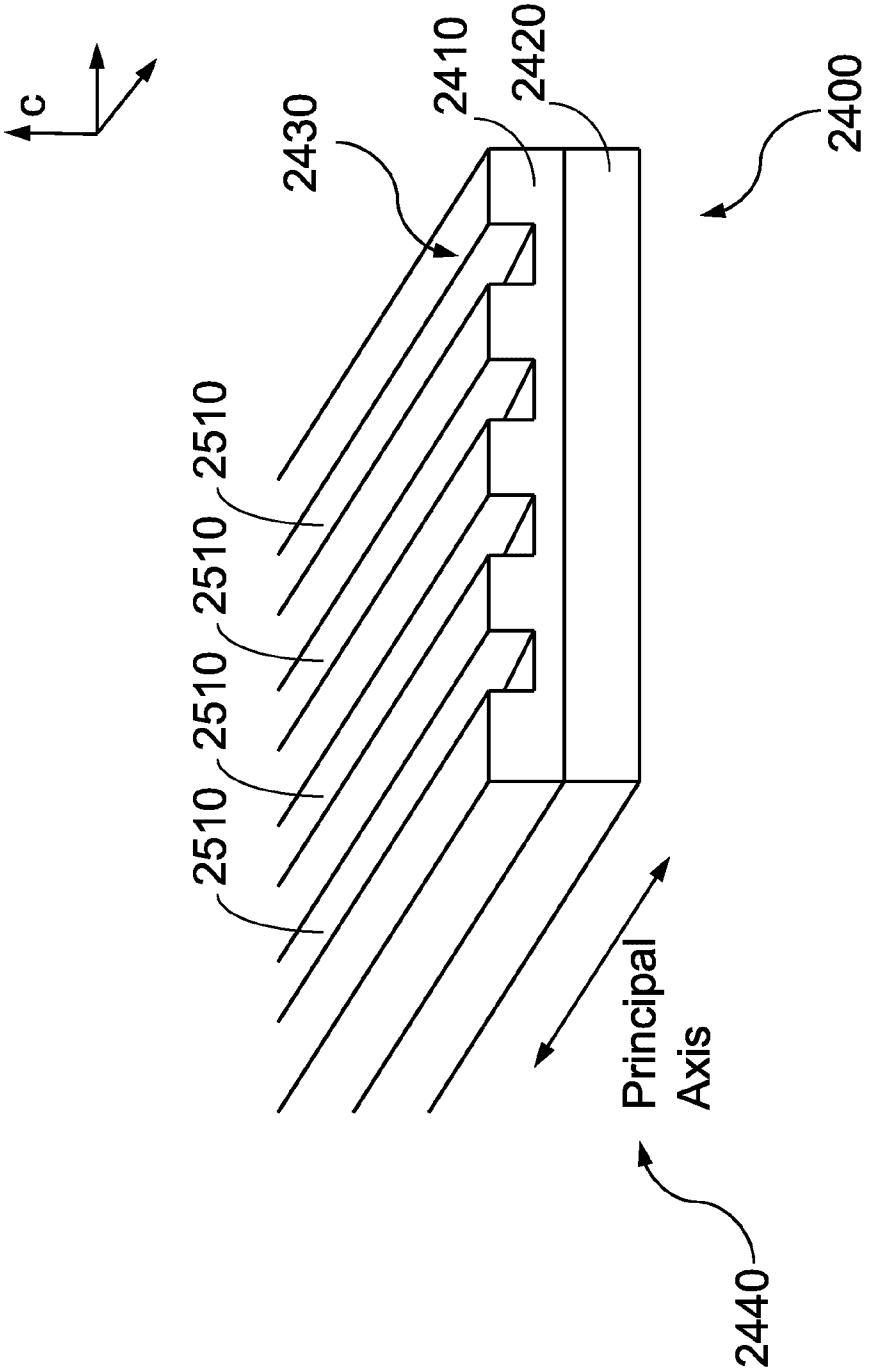

c
2430
2410
2420
2400
2510
2510
2510
2510
Principal
Axis
2440

FIG. 25

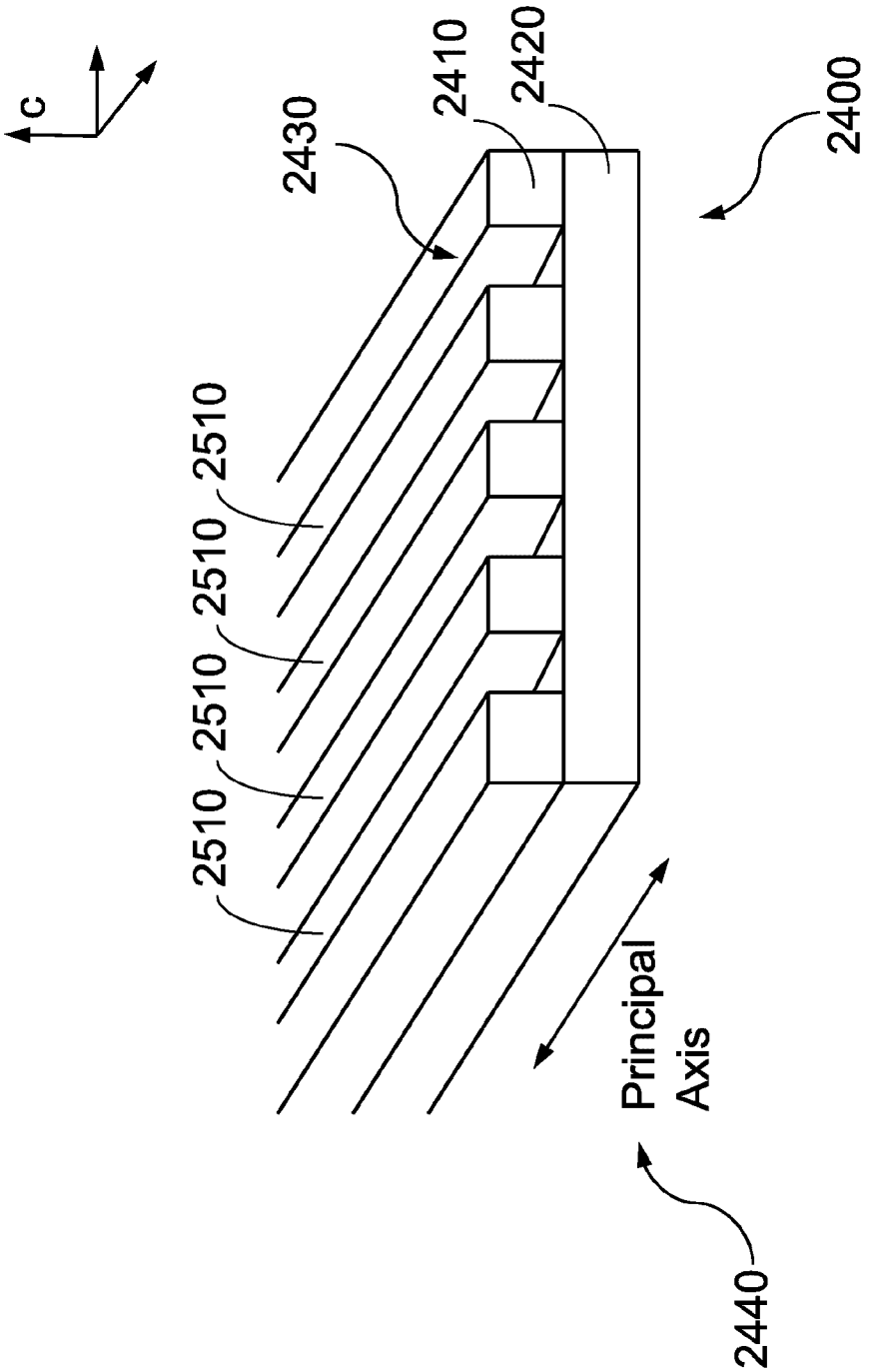

c
2430
2410
2420
2400
2510
2510
2510
2510
Principal
Axis
2440

FIG. 26

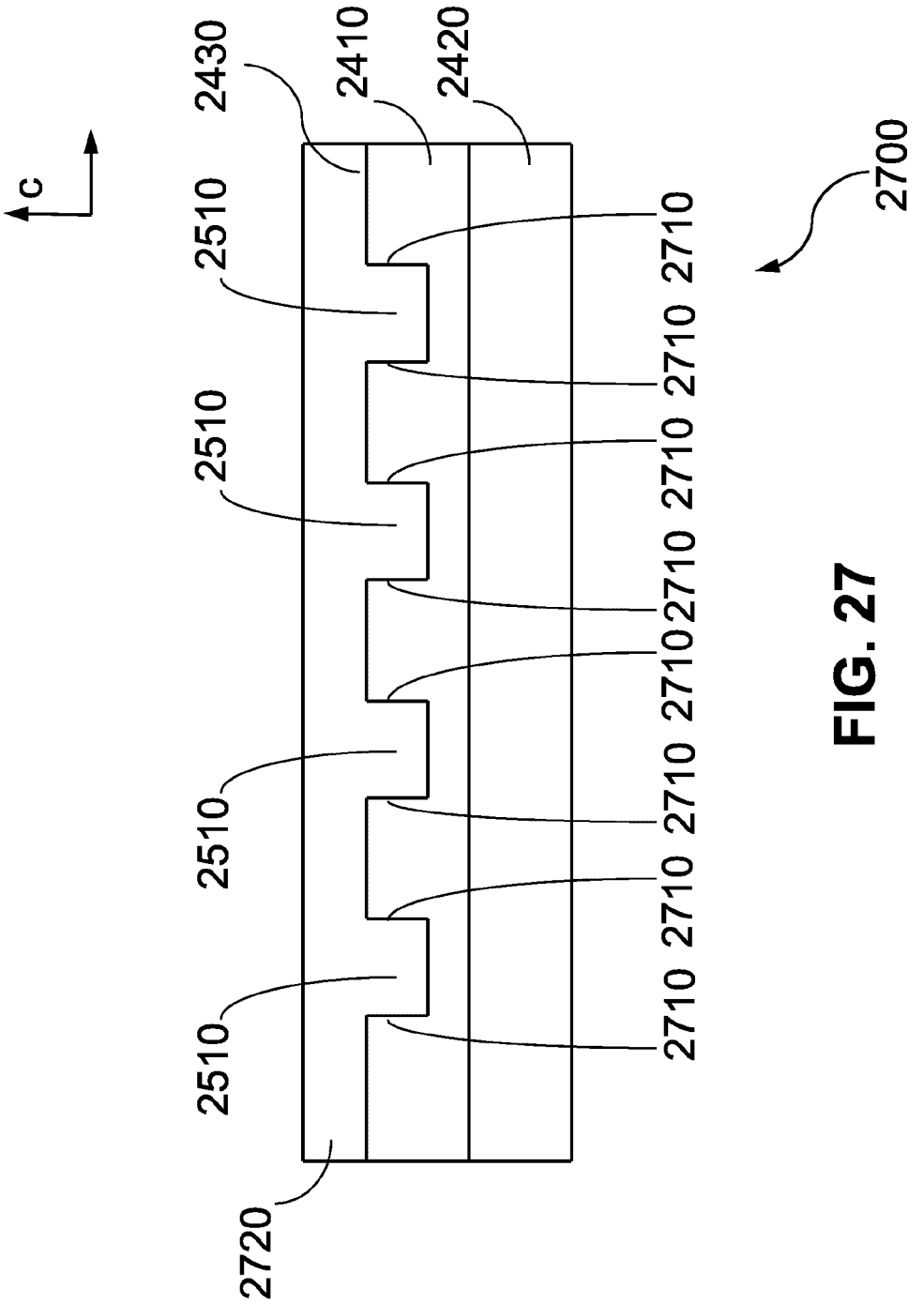

c
2430
2410
2420
2700
2510
2710
2510
2710
2510
2710
2710
2510
2710
2710
2510
2710
2710
2720

FIG. 27

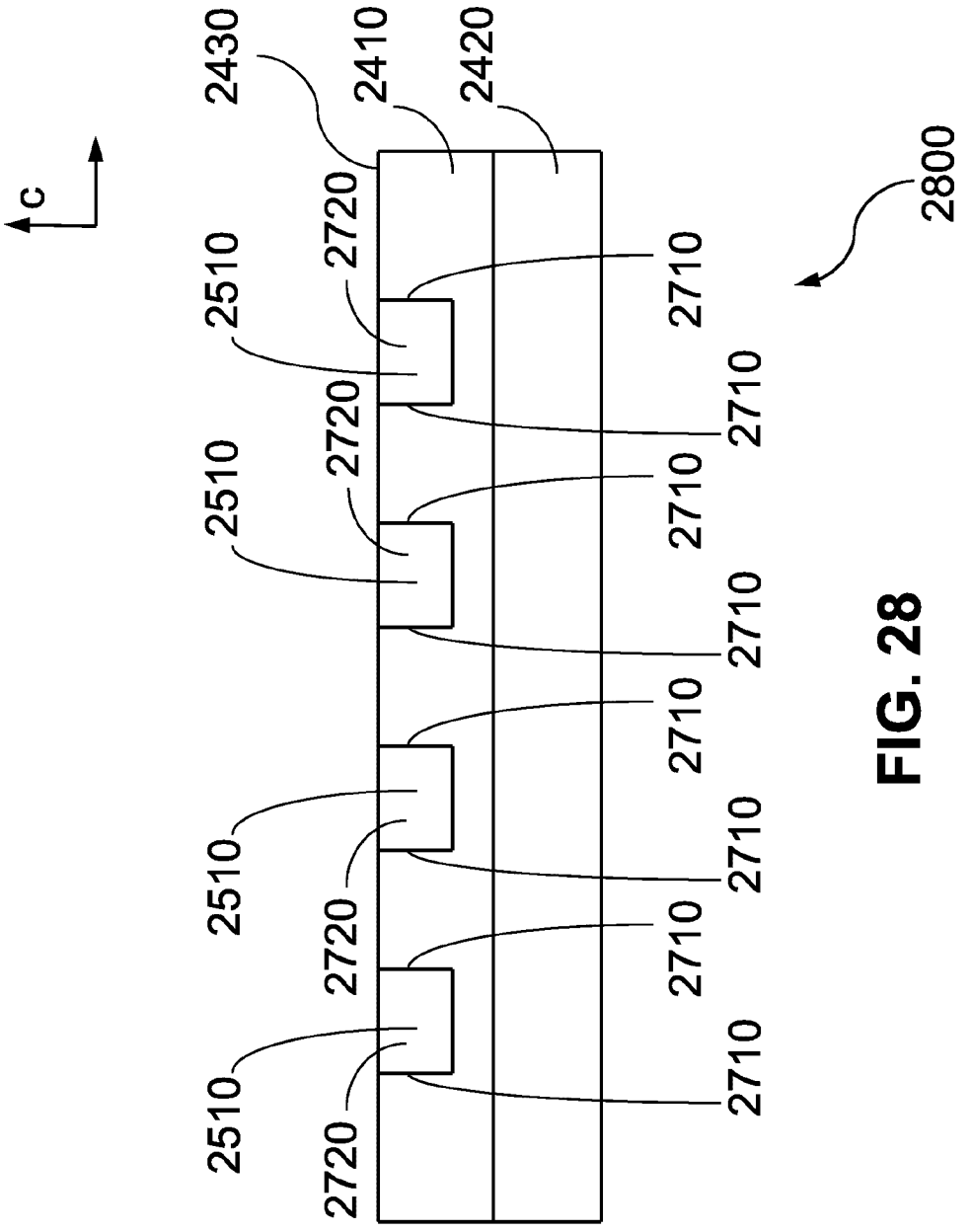

c
2430
2410
2420
2800
2720
2510
2710
2720
2510
2710
2710
2510
2710
2720
2710
2510
2720
2710

FIG. 28

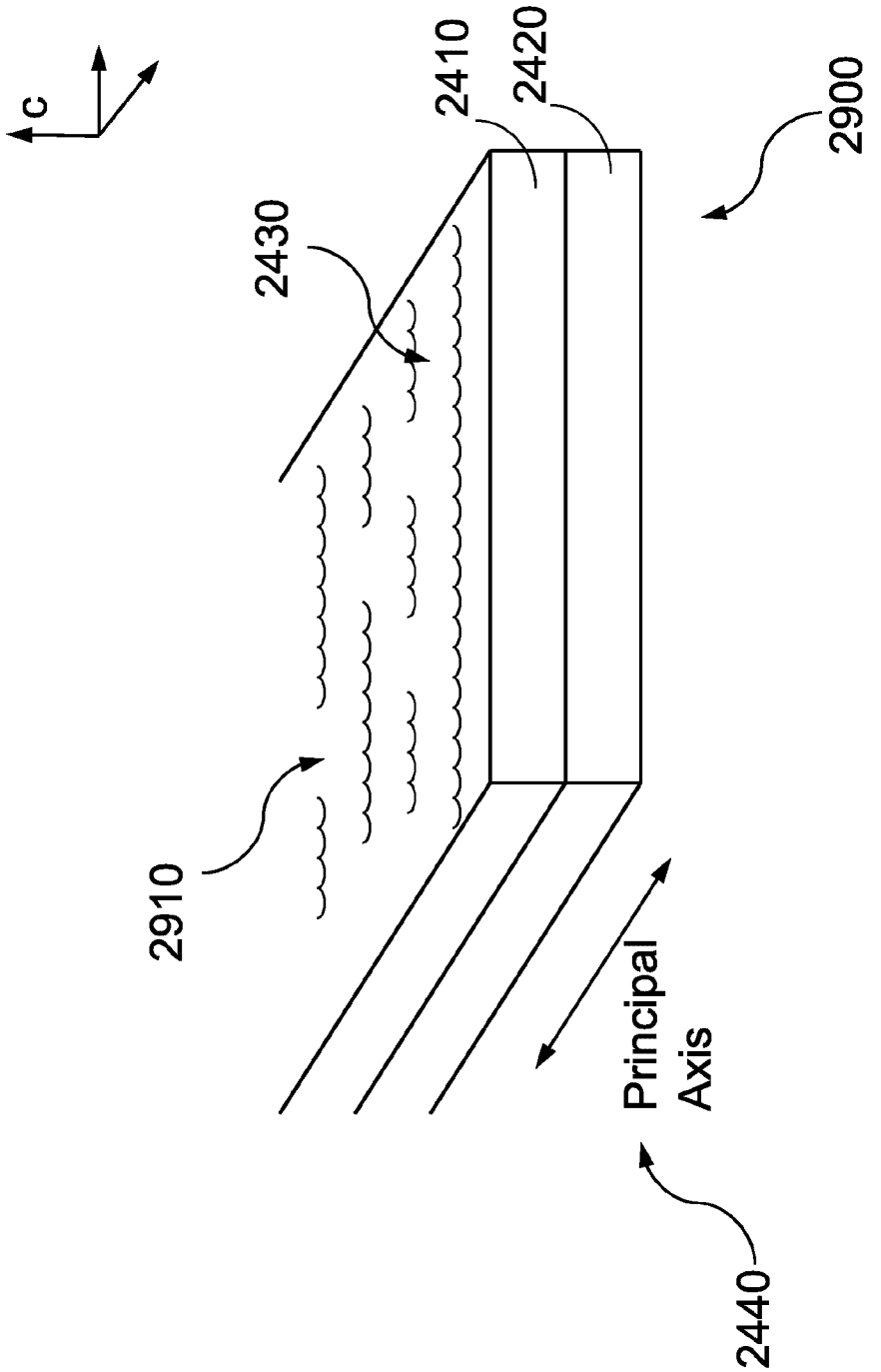


FIG. 29

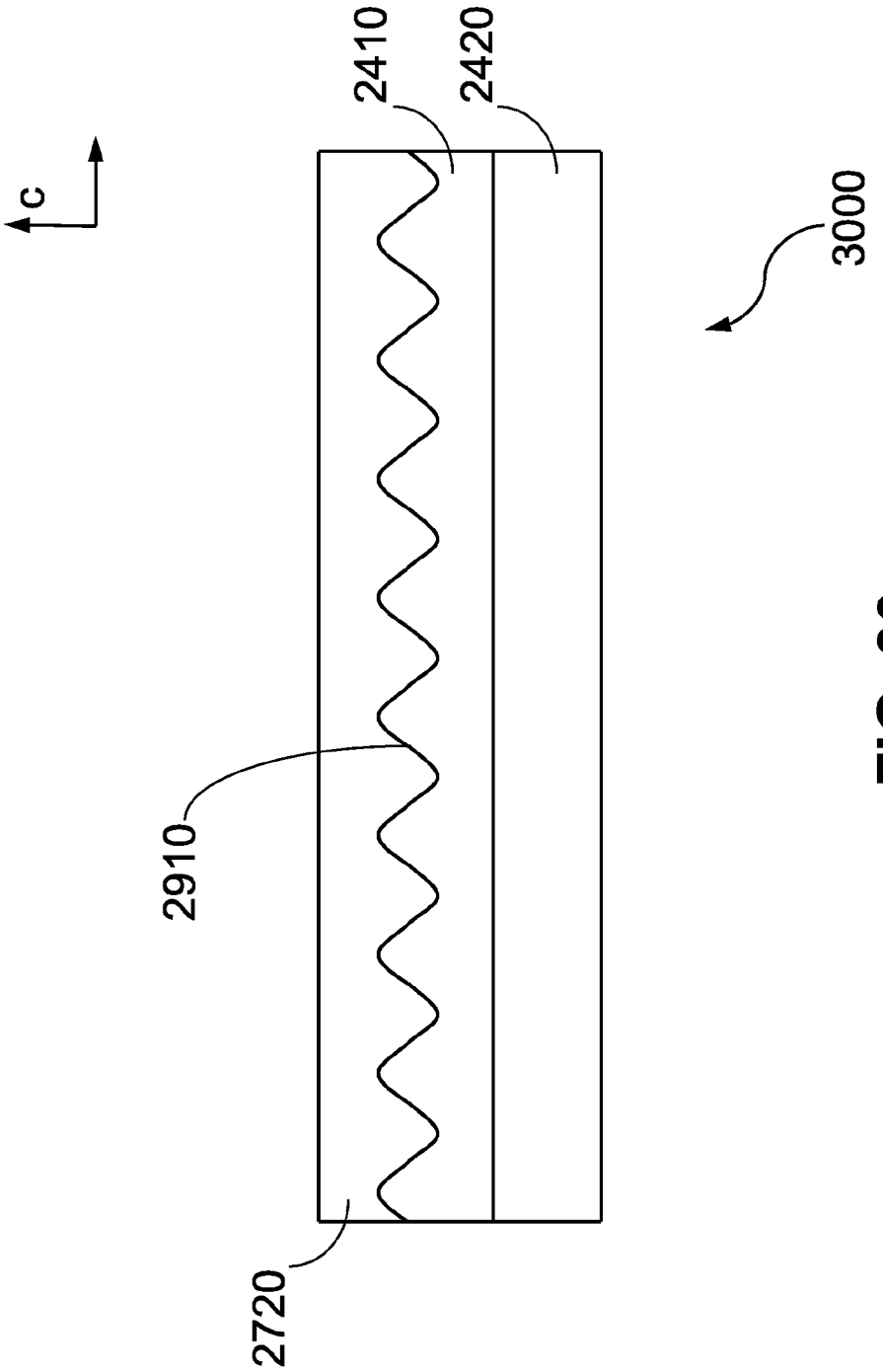


FIG. 30

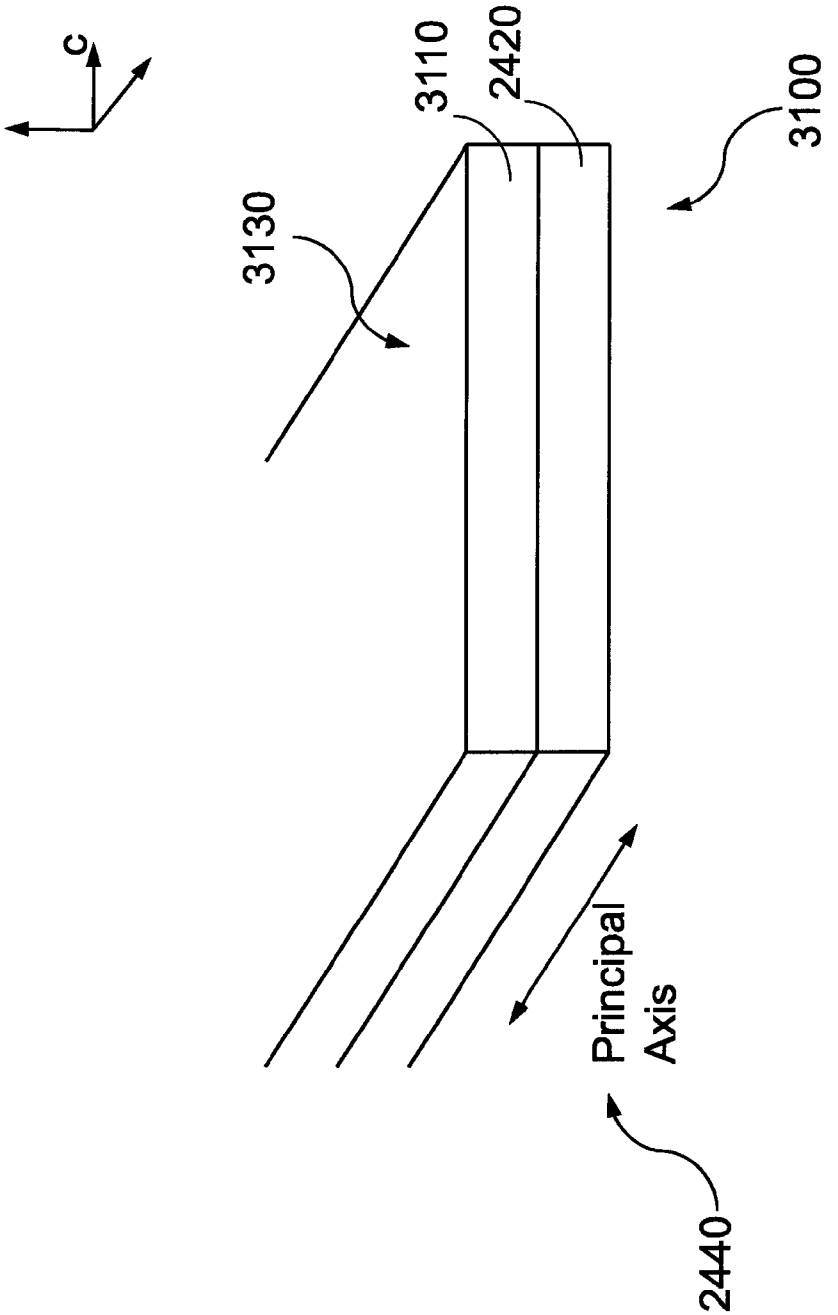


FIG. 31

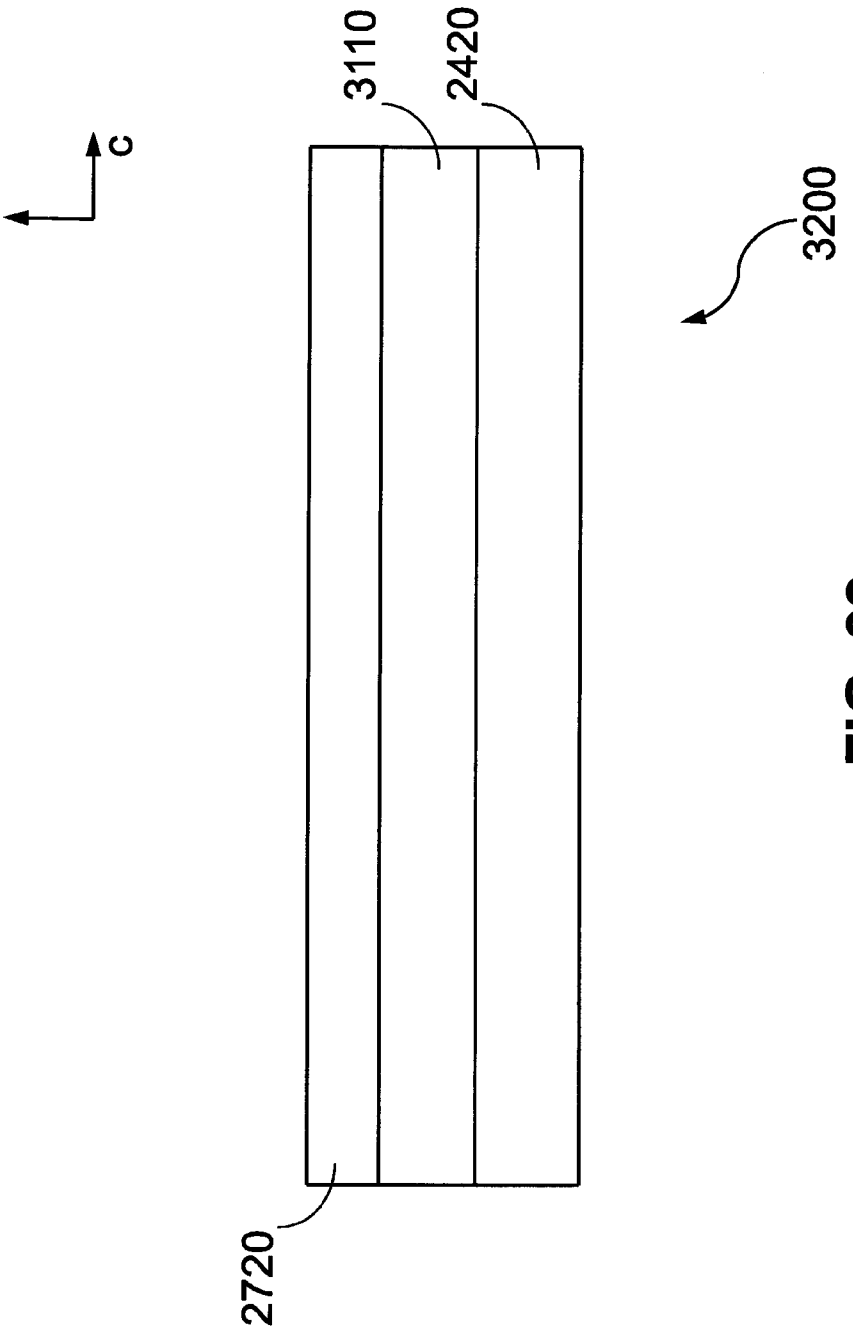


FIG. 32

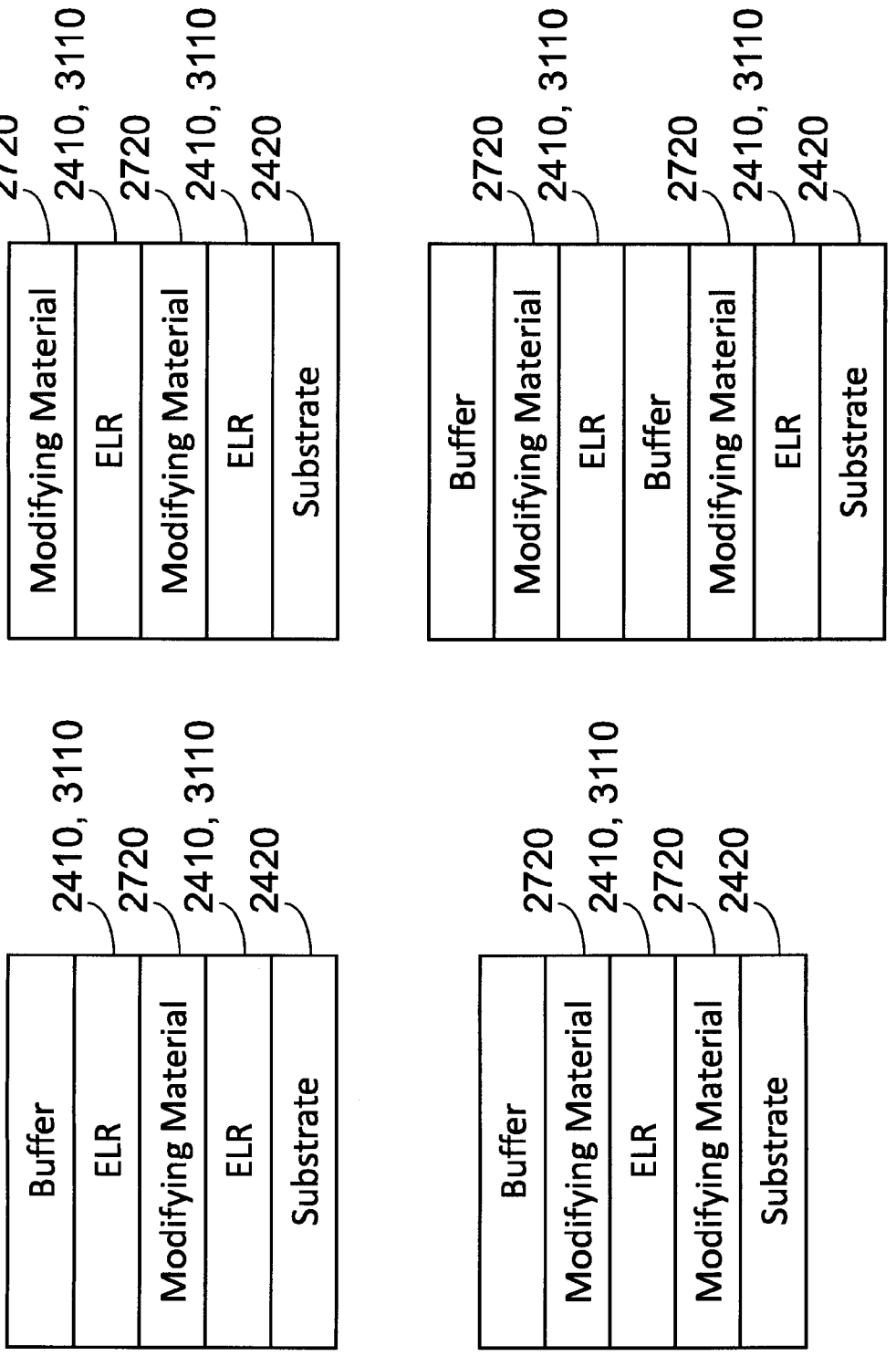

2720
2410, 3110
Modifying Material
ELR
2720
2410, 3110
Modifying Material
ELR
2420
Substrate
2720
2410, 3110
Buffer
ELR
2720
2410, 3110
Modifying Material
ELR
2420
Substrate
2410, 3110
2720
2410, 3110
Buffer
ELR
2720
2410, 3110
Modifying Material
ELR
2420
Substrate
2720
2410, 3110
Buffer
Modifying Material
ELR
2720
2410, 3110
Modifying Material
2420
Substrate

FIG. 33

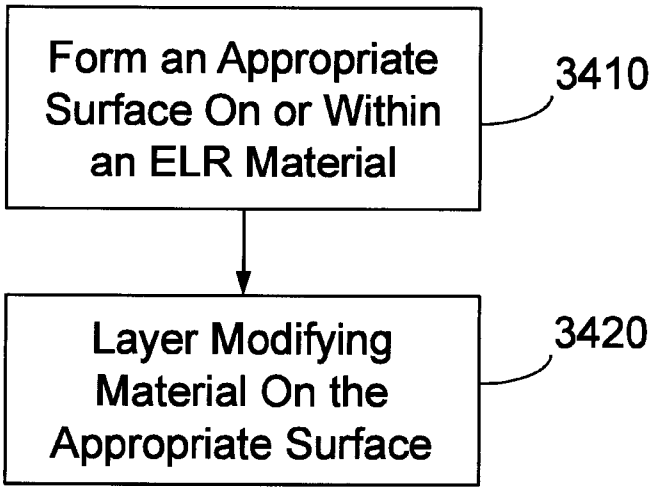

Form an Appropriate Surface On or Within an ELR Material
3410
Layer Modifying Material On the Appropriate Surface
3420

FIG. 34

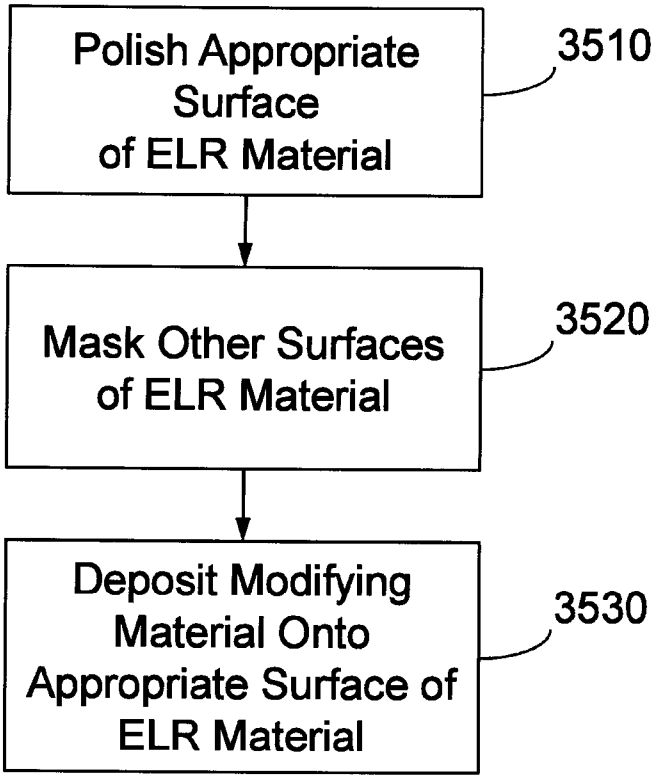

Polish Appropriate Surface of ELR Material
3510
Mask Other Surfaces of ELR Material
3520
Deposit Modifying Material Onto Appropriate Surface of ELR Material
3530

FIG. 35

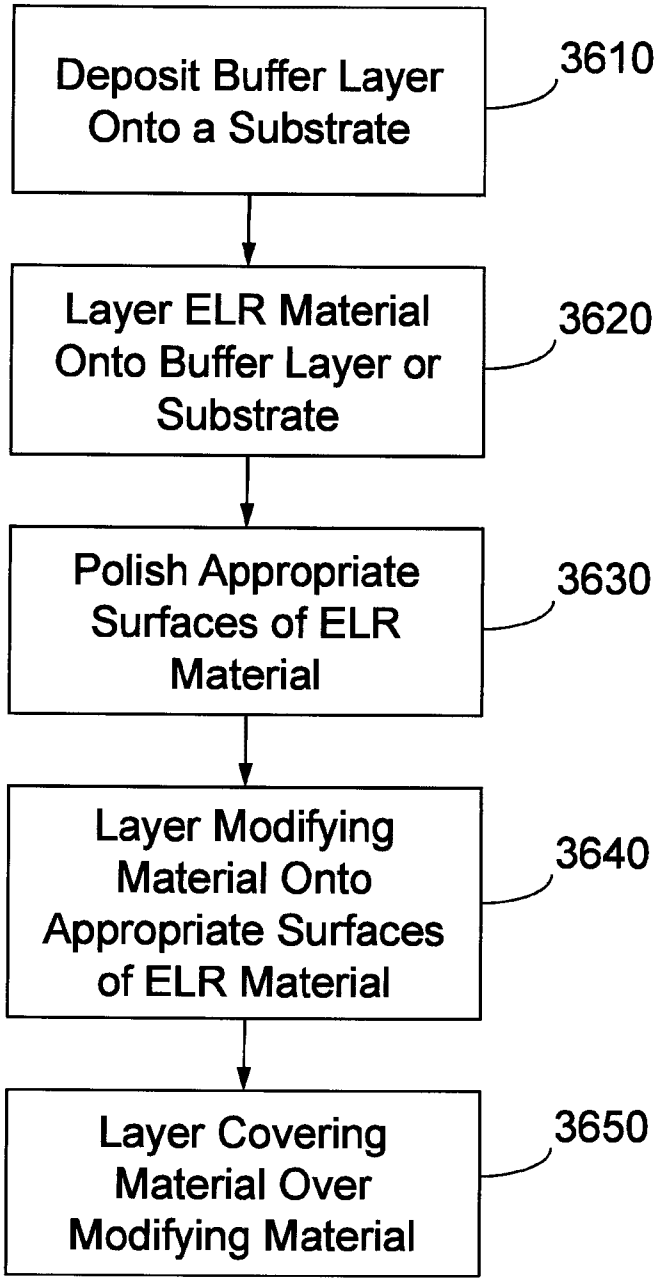

Deposit Buffer Layer Onto a Substrate
3610
Layer ELR Material Onto Buffer Layer or Substrate
3620
Polish Appropriate Surfaces of ELR Material
3630
Layer Modifying Material Onto Appropriate Surfaces of ELR Material
3640
Layer Covering Material Over Modifying Material
3650

FIG. 36

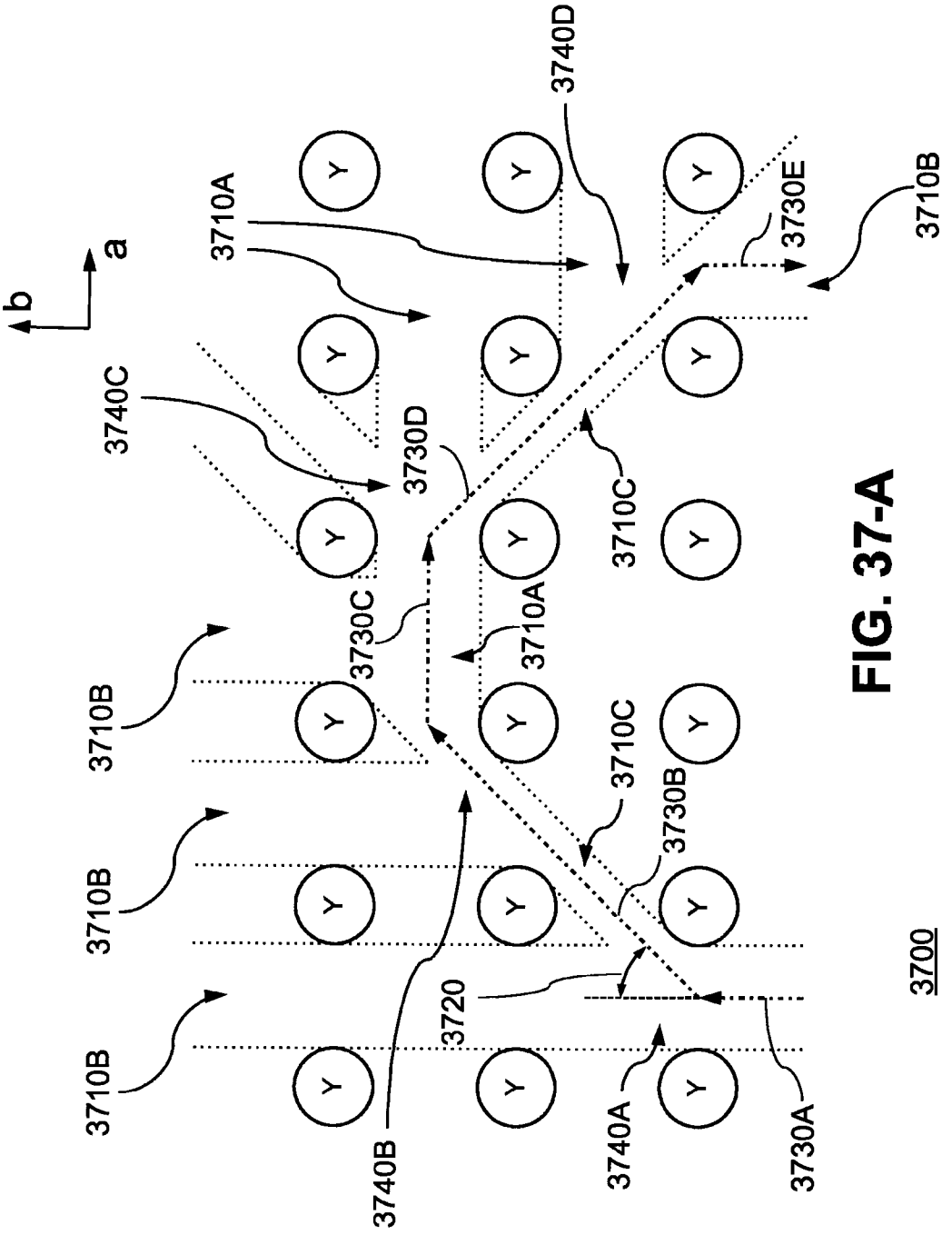

b
a
3710A
3740D
3740C
3730D
3730C
3710A
3710C
3730E
3710B
3710B
3710B
3710C
3730B
3720
3740B
3740A
3730A
3700

FIG. 37-A

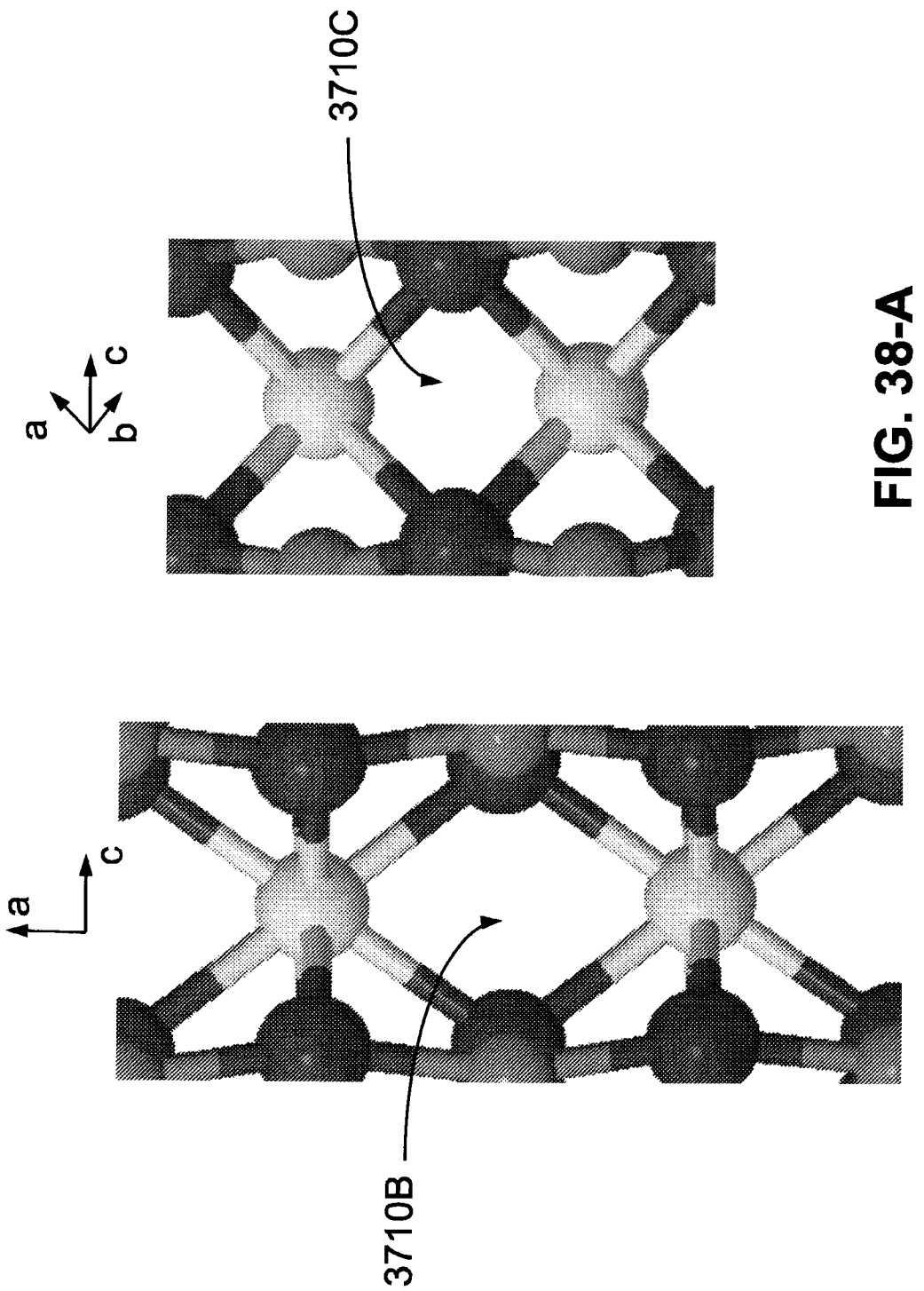


FIG. 38-A

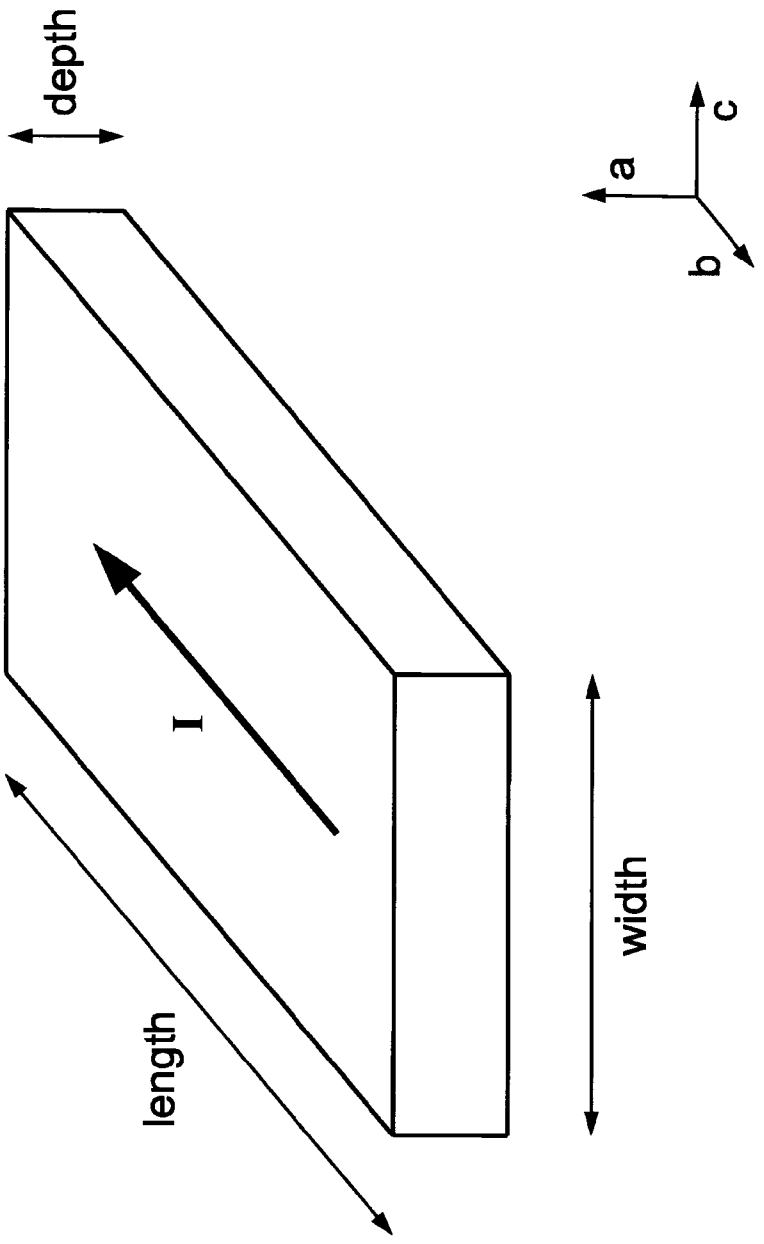


FIG. 39-A

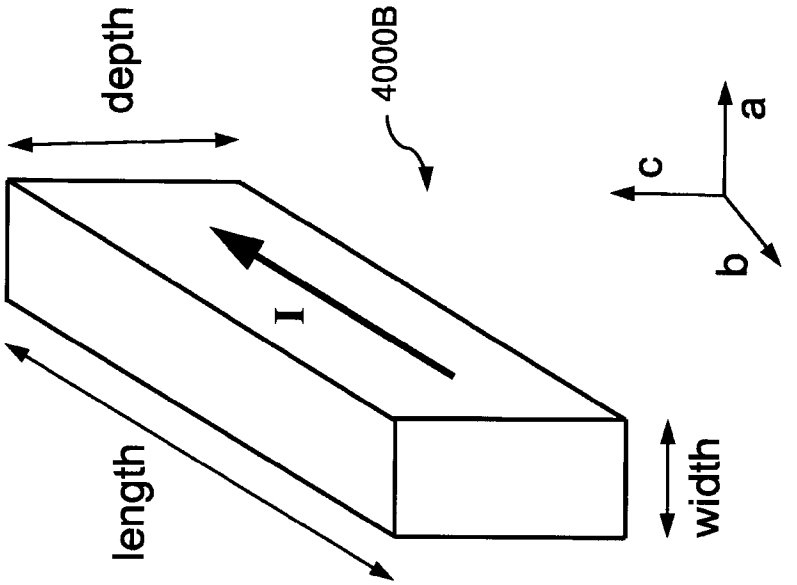


FIG. 40B-A

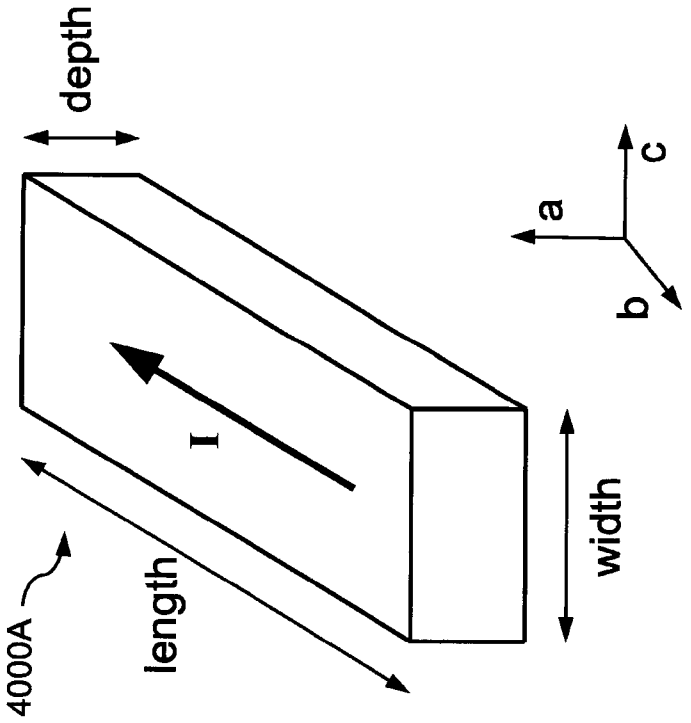


FIG. 40A-A

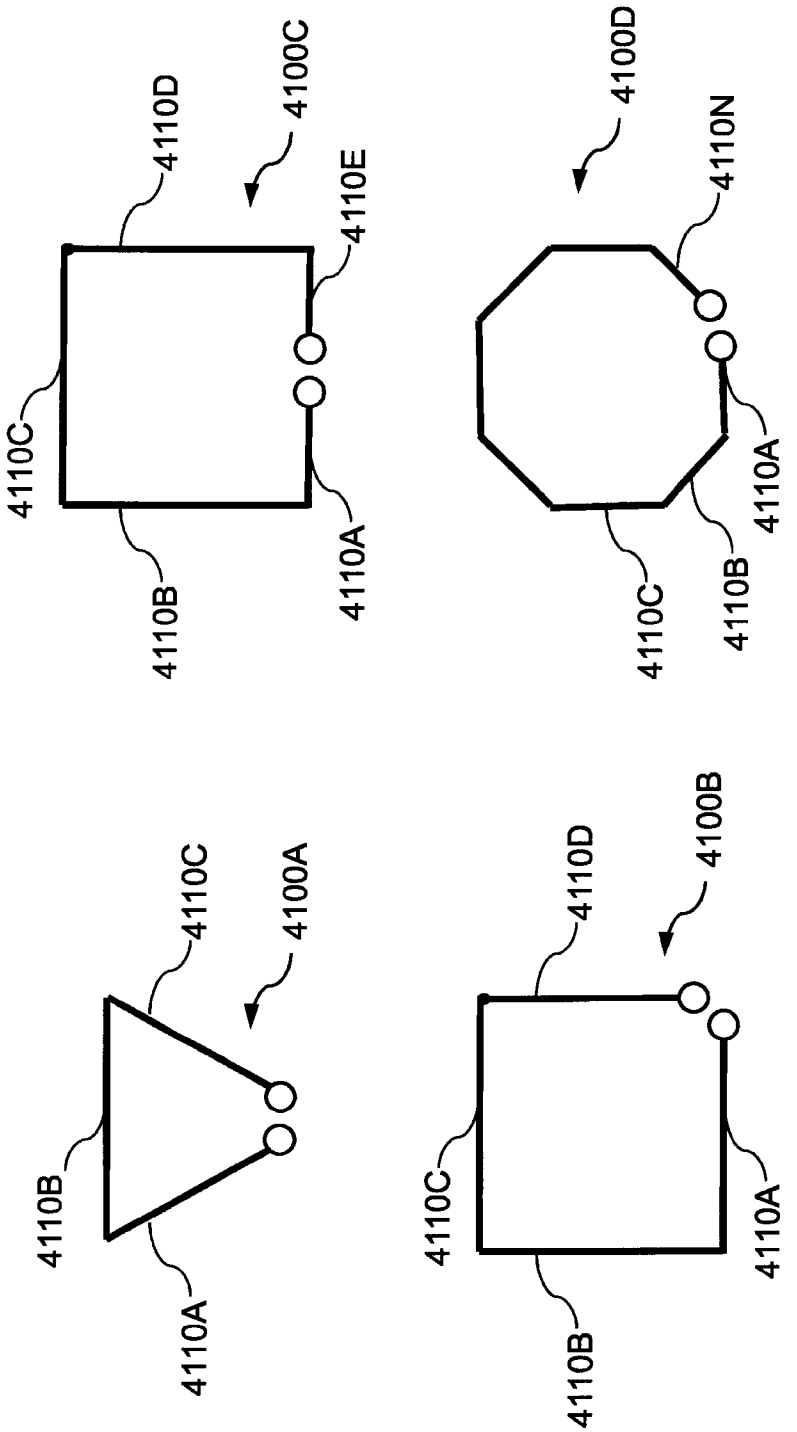

4100C
4110D
4110E
4110C
4110B
4110A
4100D
4110N
4110C
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4110C
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4100B
4110D
4110C
4110B
4110A

FIG. 41-A

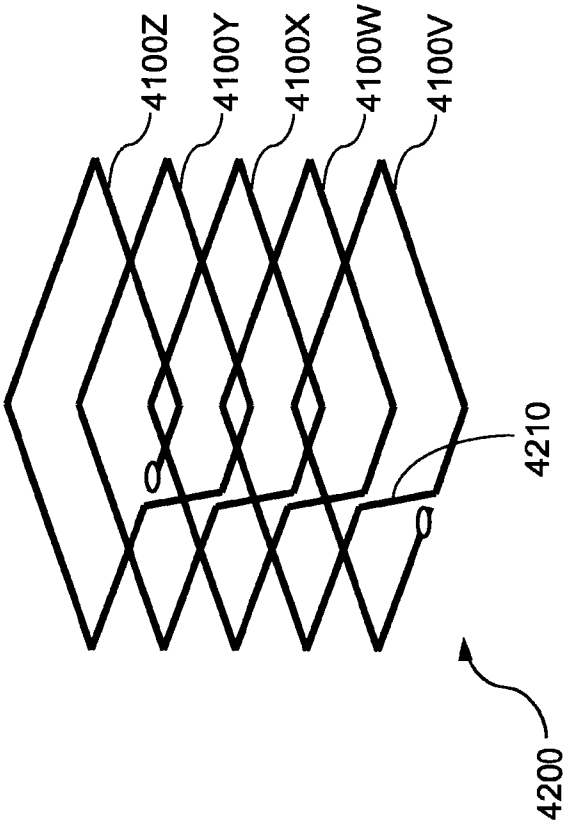


FIG. 42-A

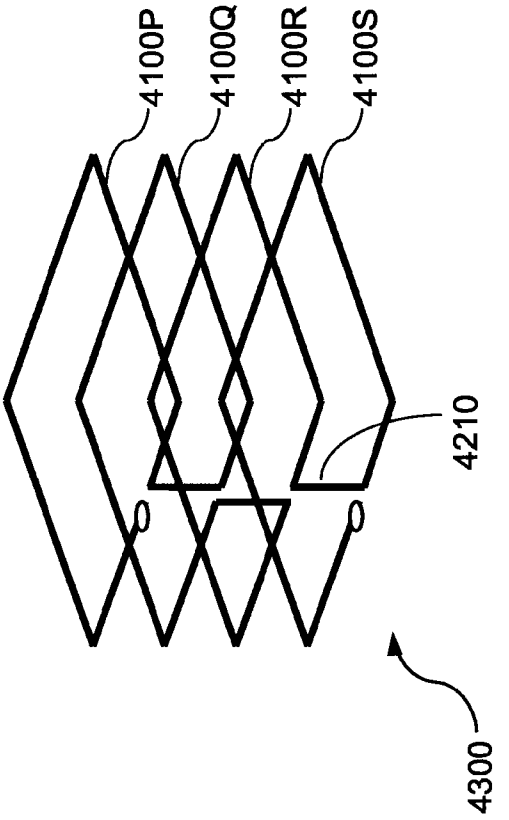


FIG. 43-A

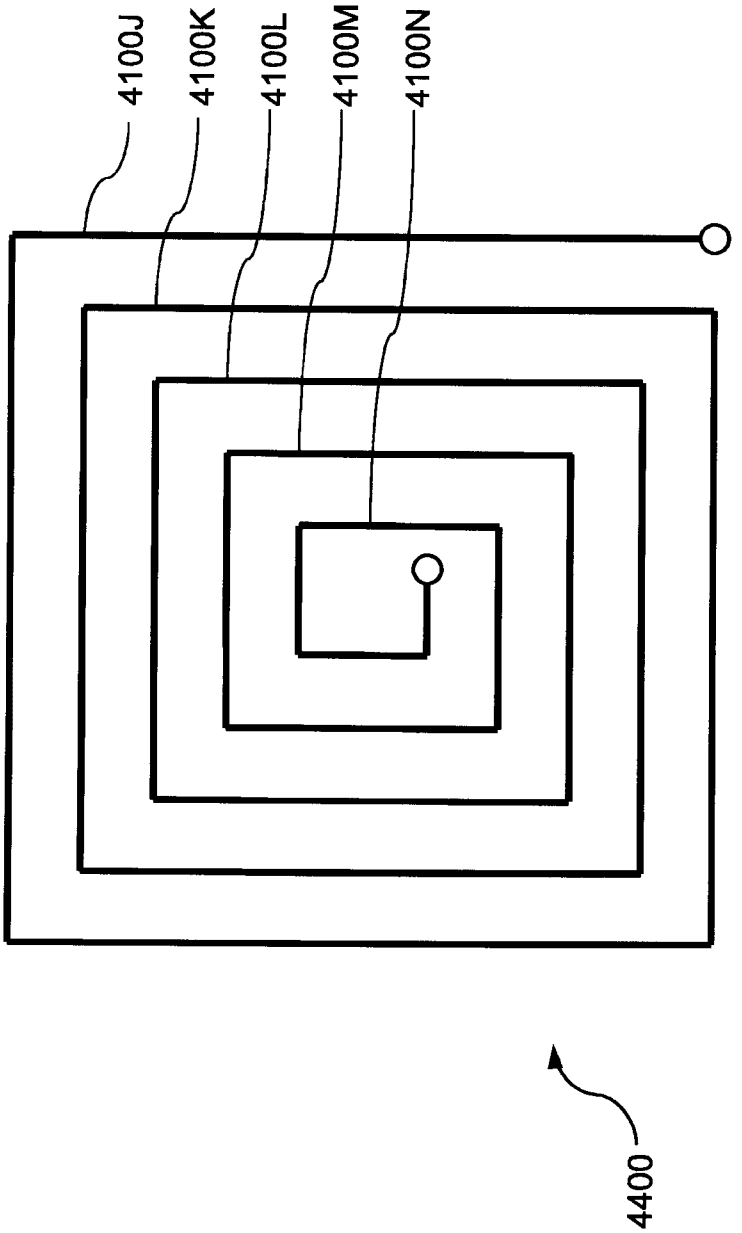


FIG. 44-A

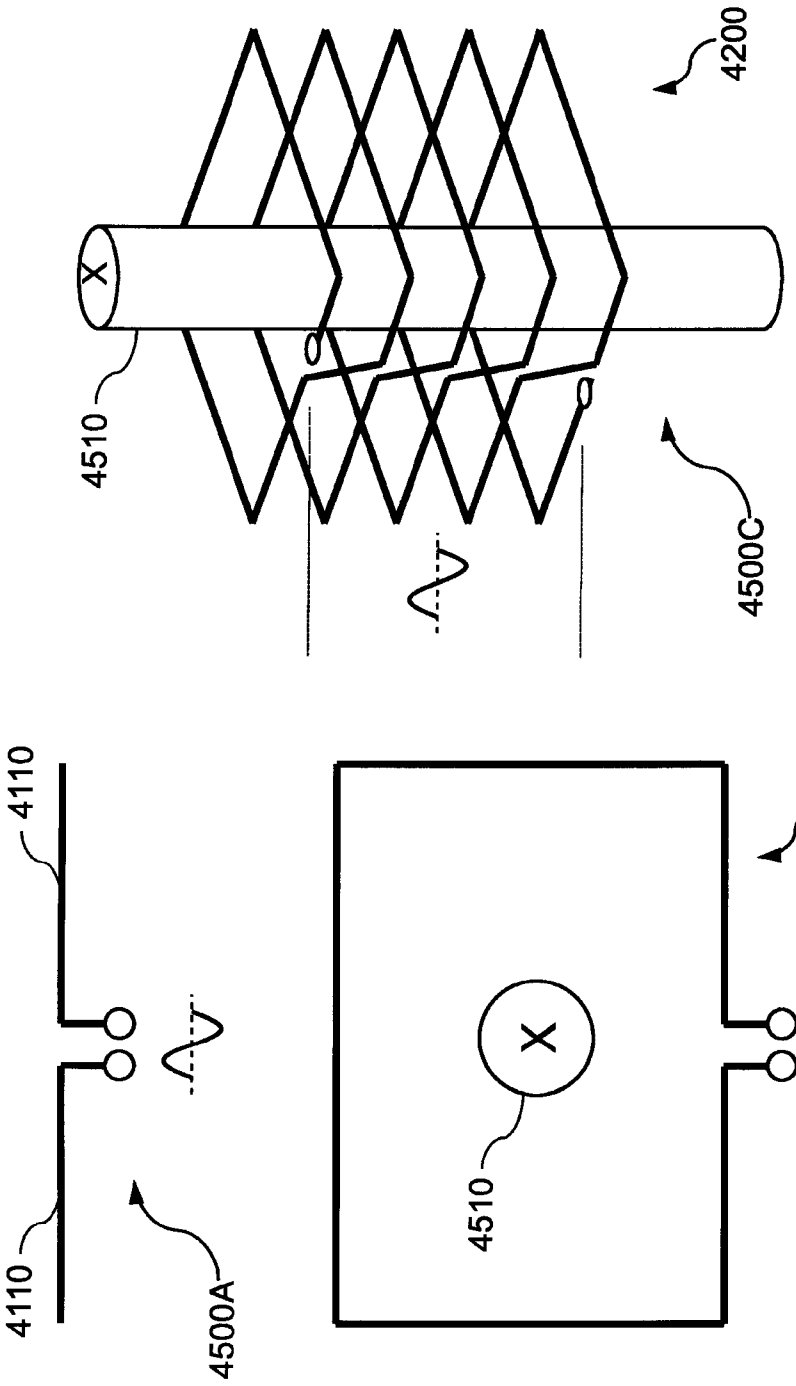


FIG. 45A-A

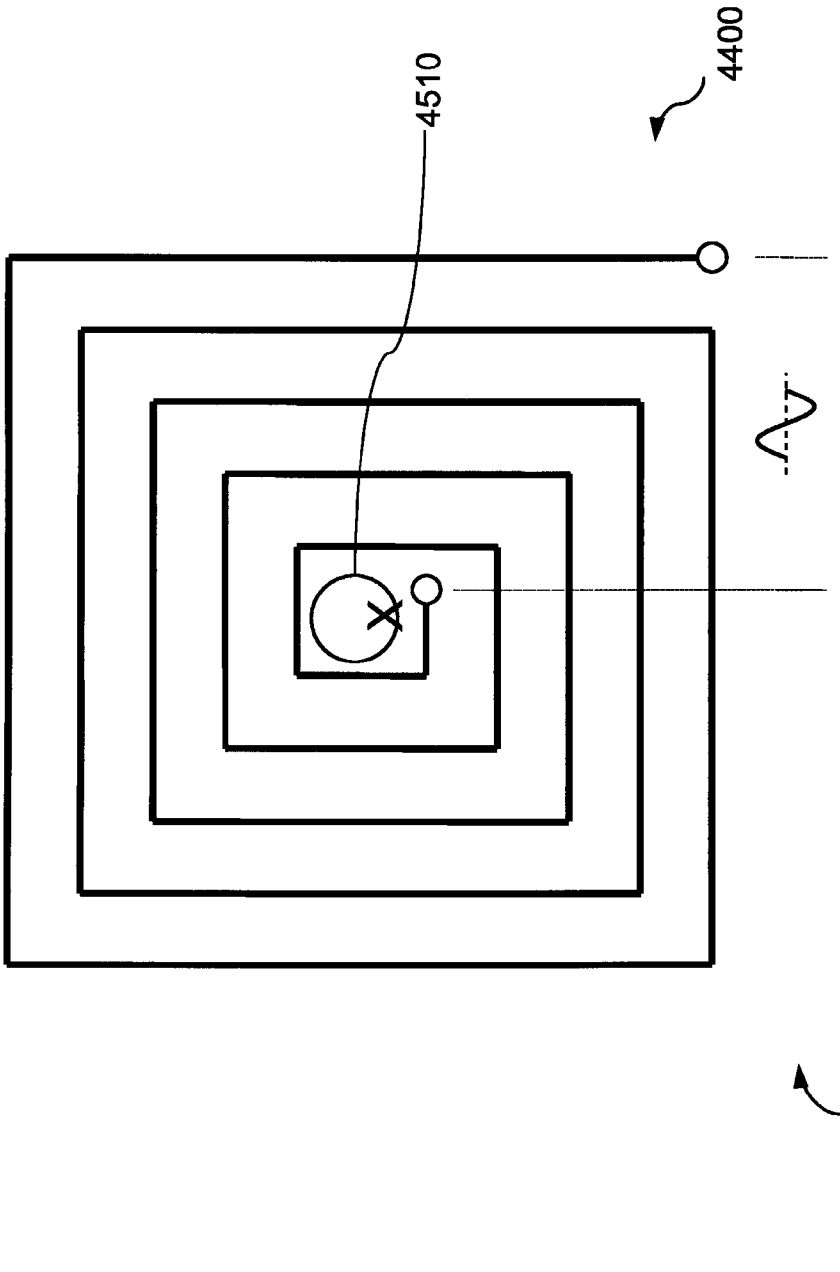


FIG. 45B-A

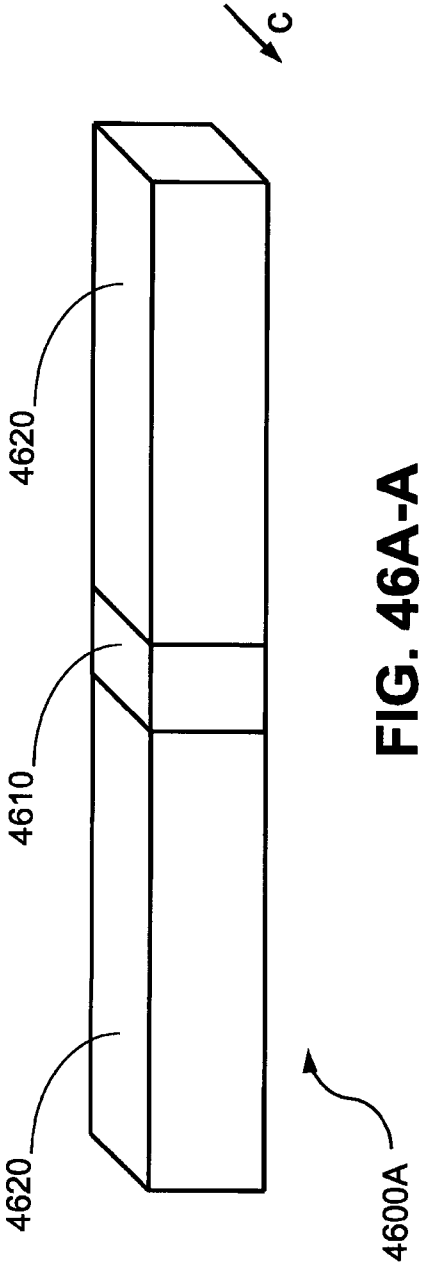


FIG. 46A-A

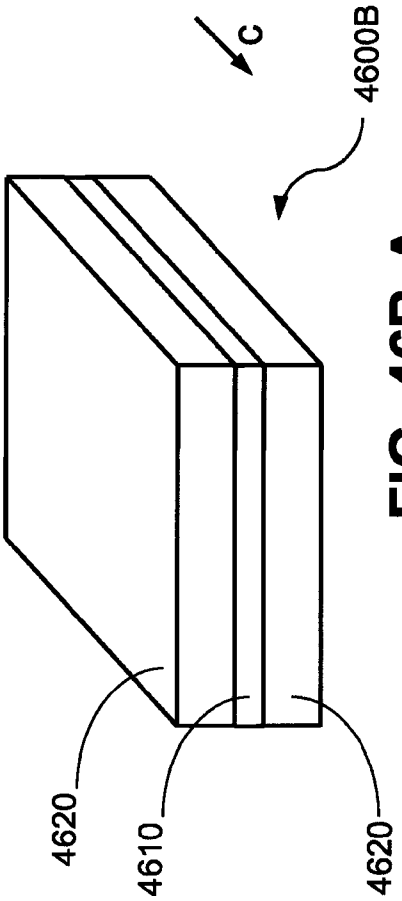


FIG. 46B-A

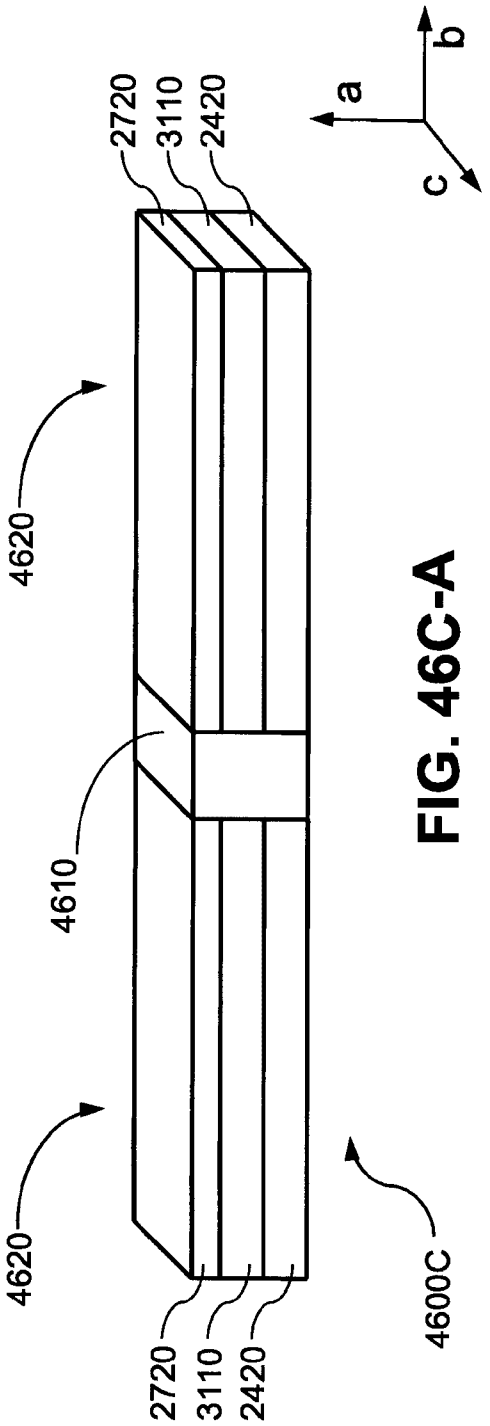


FIG. 46C-A

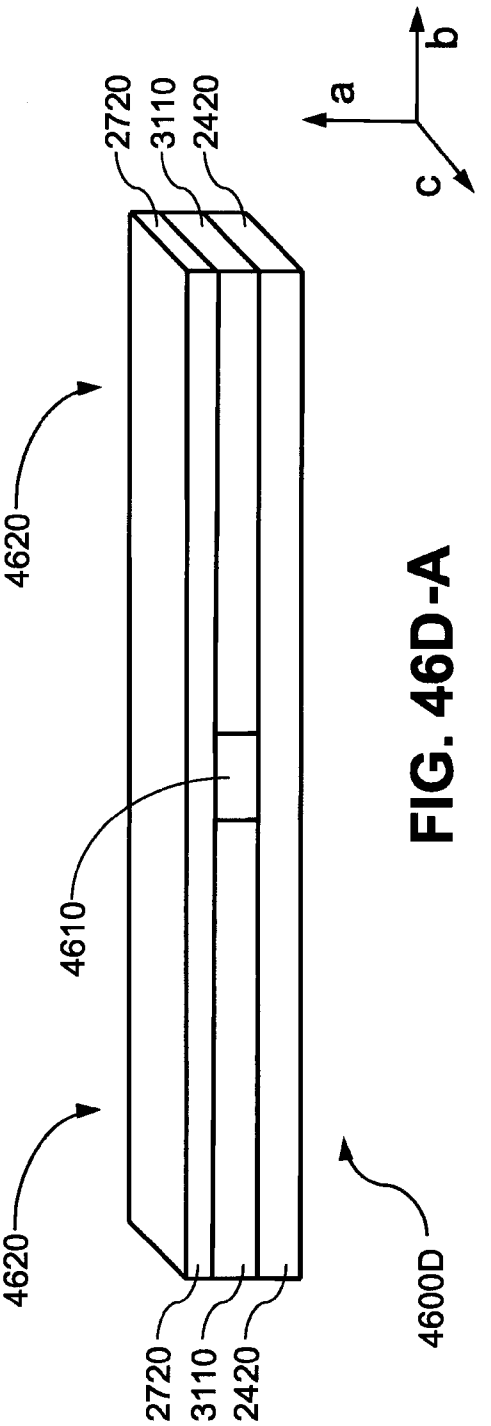


FIG. 46D-A

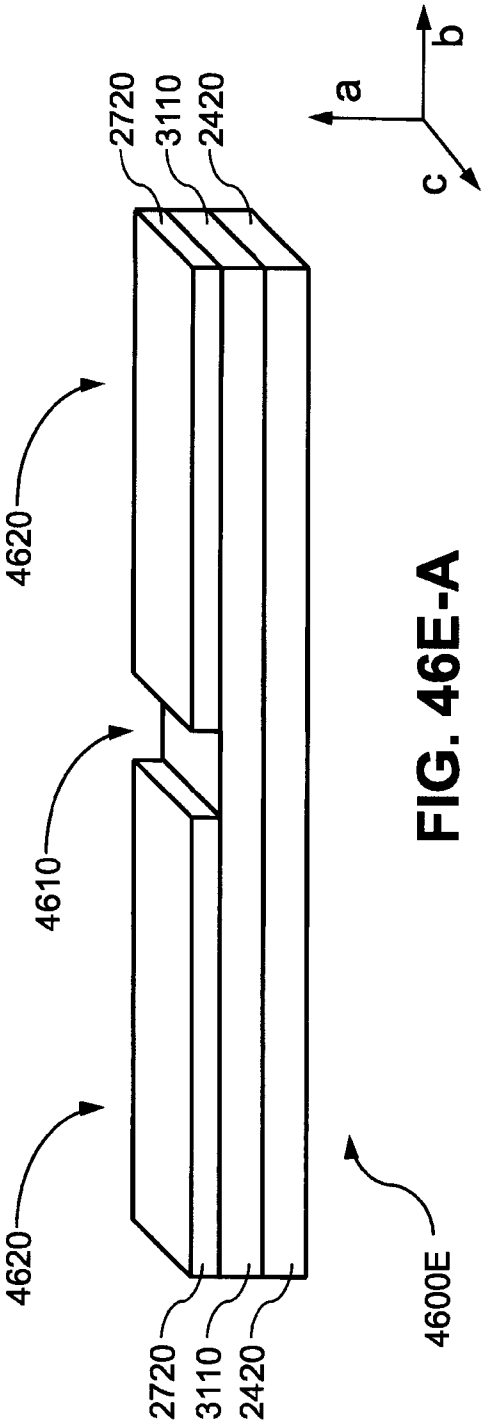


FIG. 46E-A

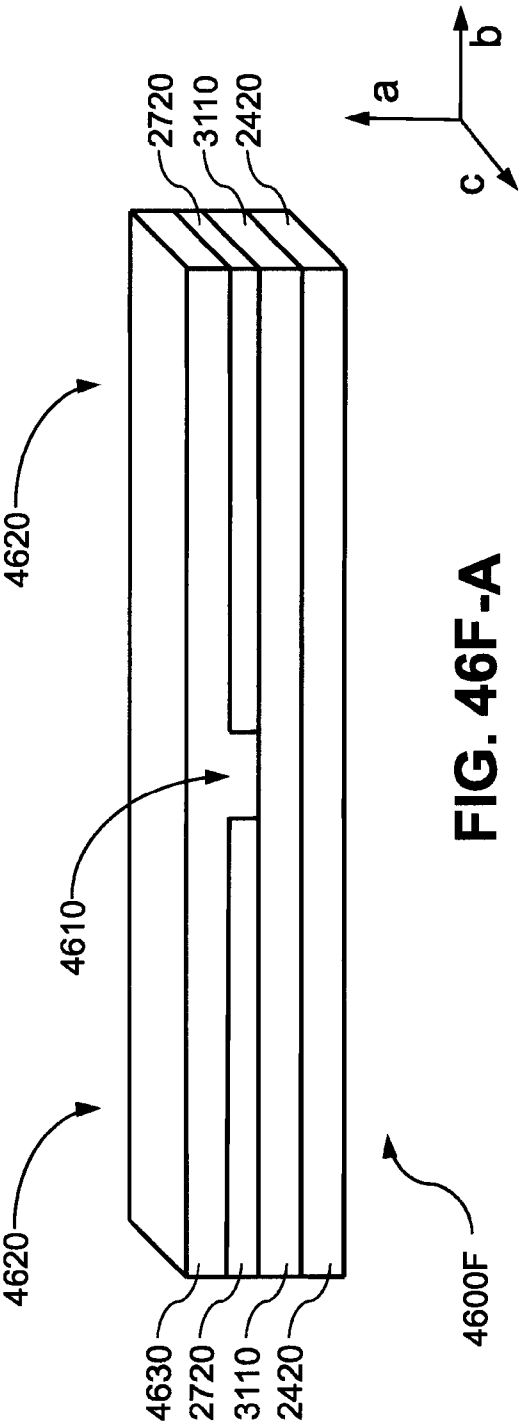


FIG. 46F-A

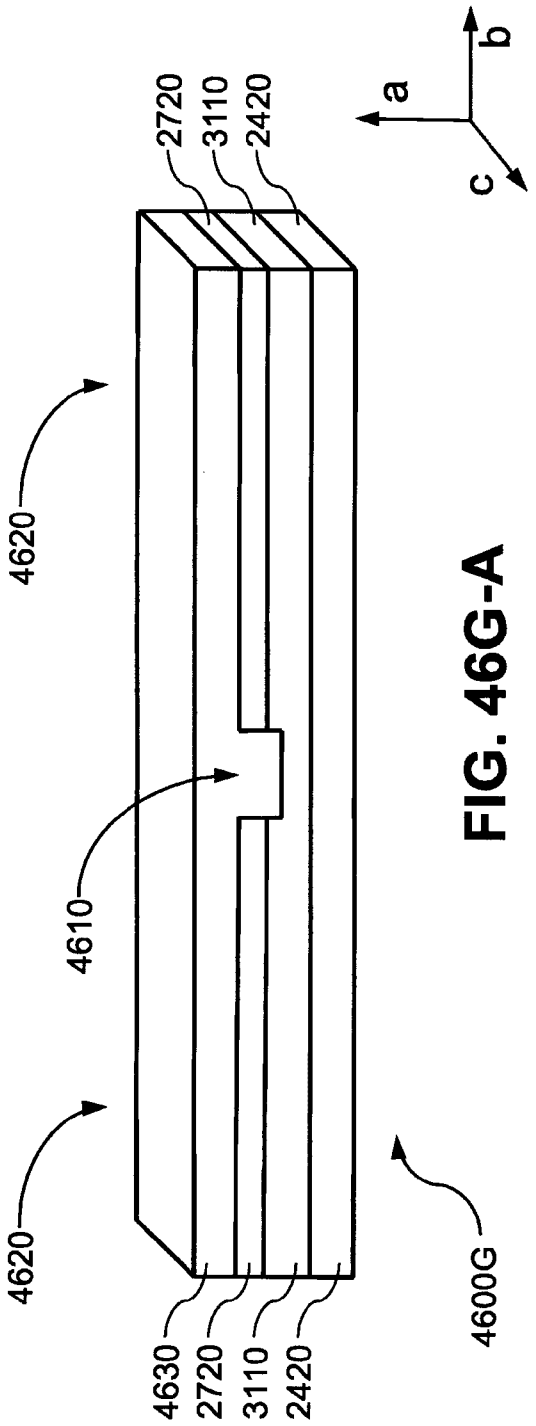


FIG. 46G-A

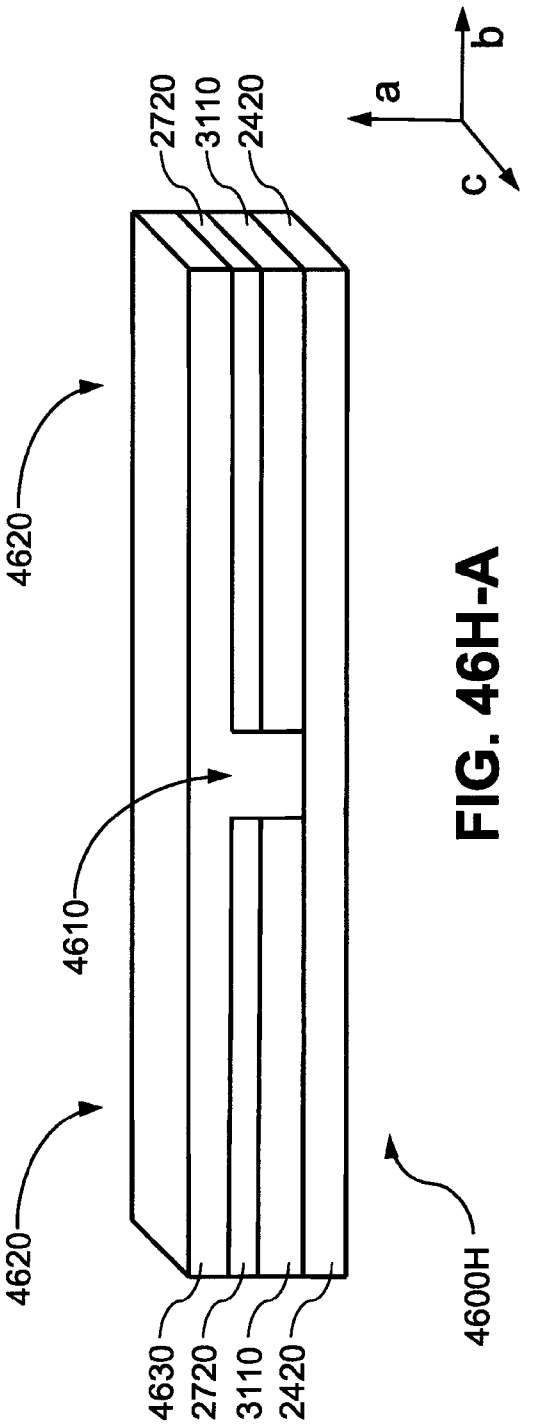


FIG. 46H-A

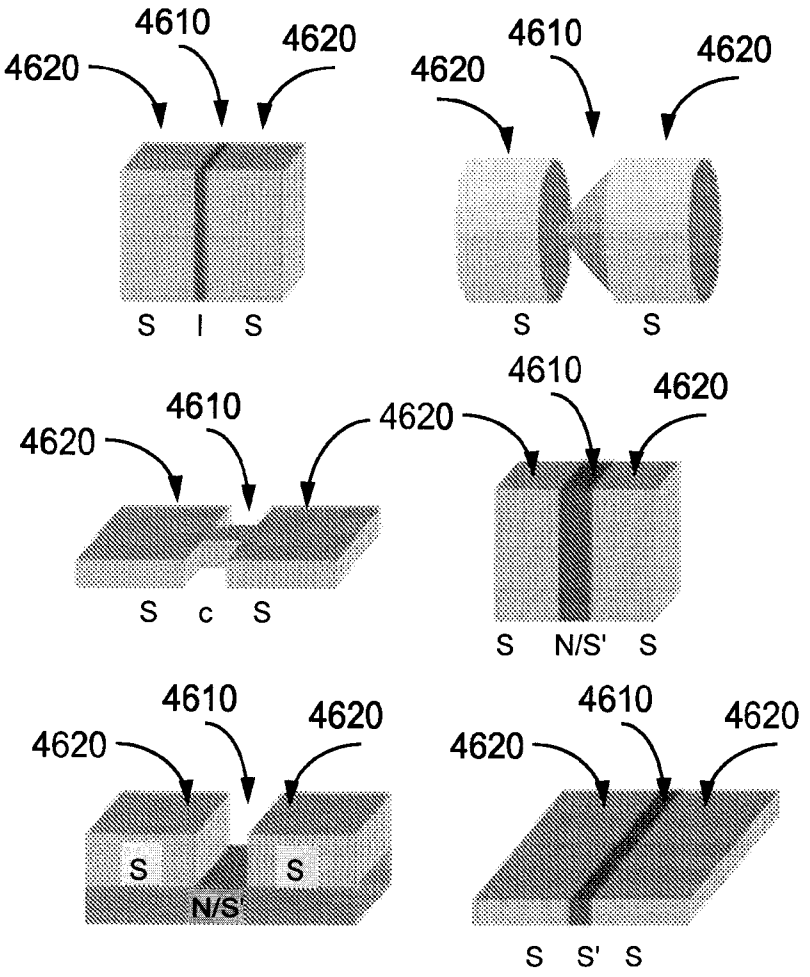

4610
4620
4620
S I S
4610
4620
4620
S S
4610
4620
4620
S c S
4610
4620
4620
S N/S' S
4610
4620
4620
S
S
N/S'
4610
4620
4620
S S' S

FIG. 46I-A

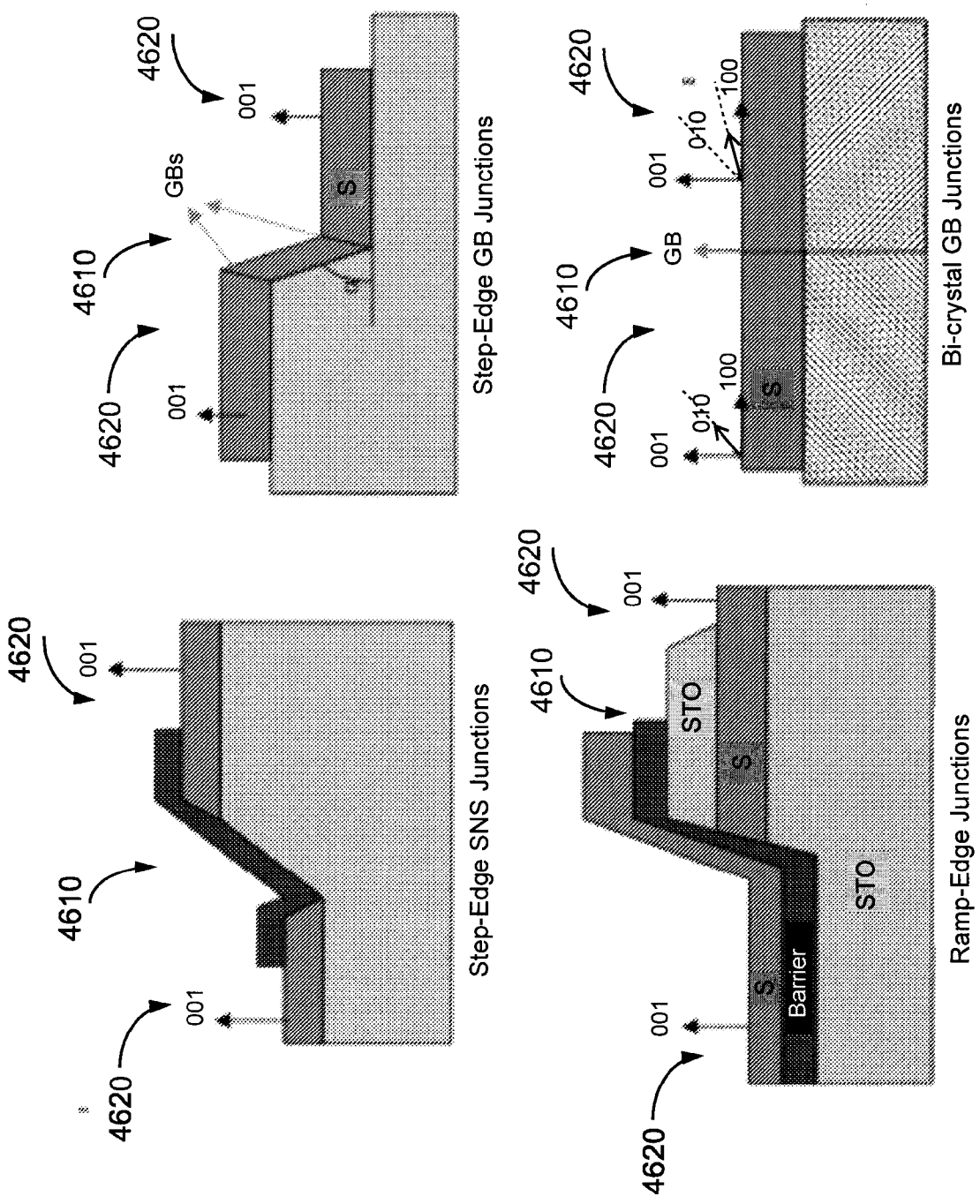

4620
001
4610
4620
001
Step-Edge SNS Junctions
4620
001
4610
GBs
4620
001
S
Step-Edge GB Junctions
4620
001
STO
4610
S
S
Barrier
STO
4620
001
Ramp-Edge Junctions
4620
001
010
100
4610
GB
4620
001
010
100
S
Bi-crystal GB Junctions

FIG. 46J-A

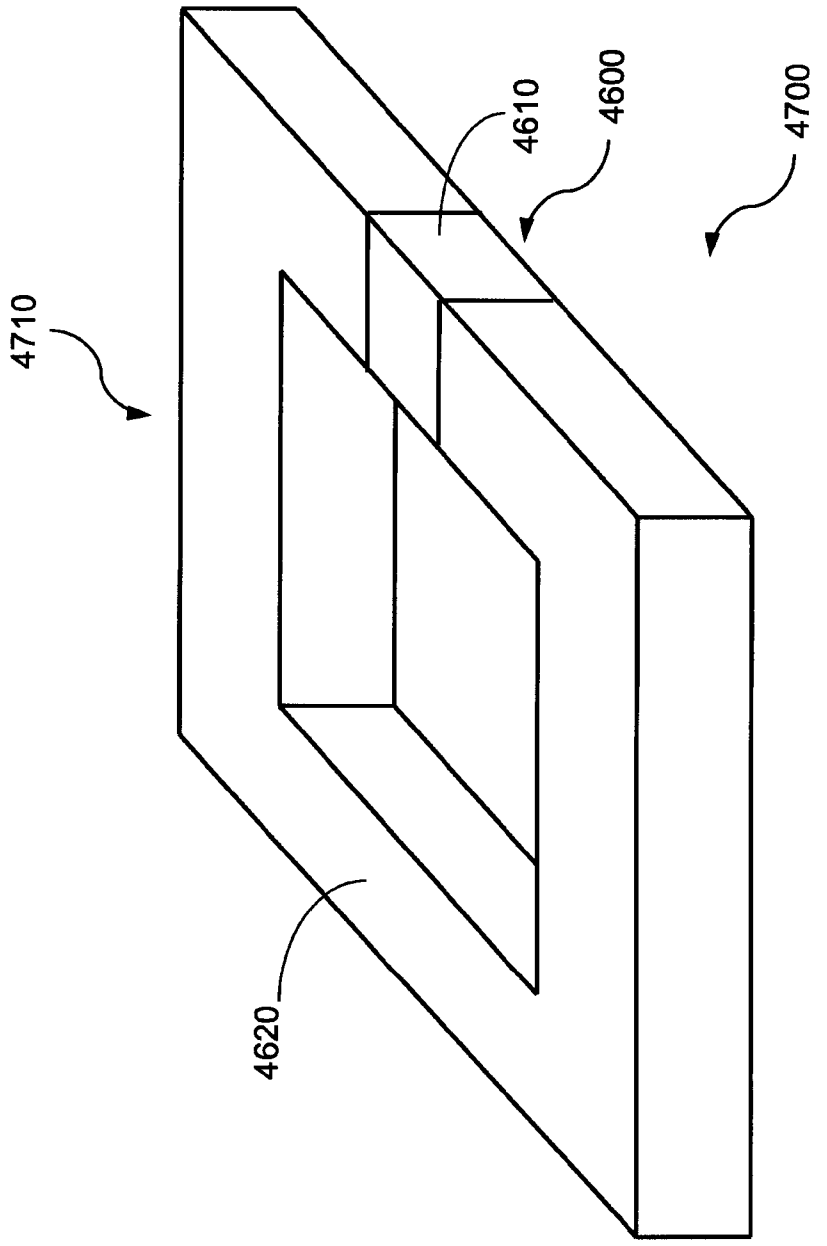


FIG. 47-A

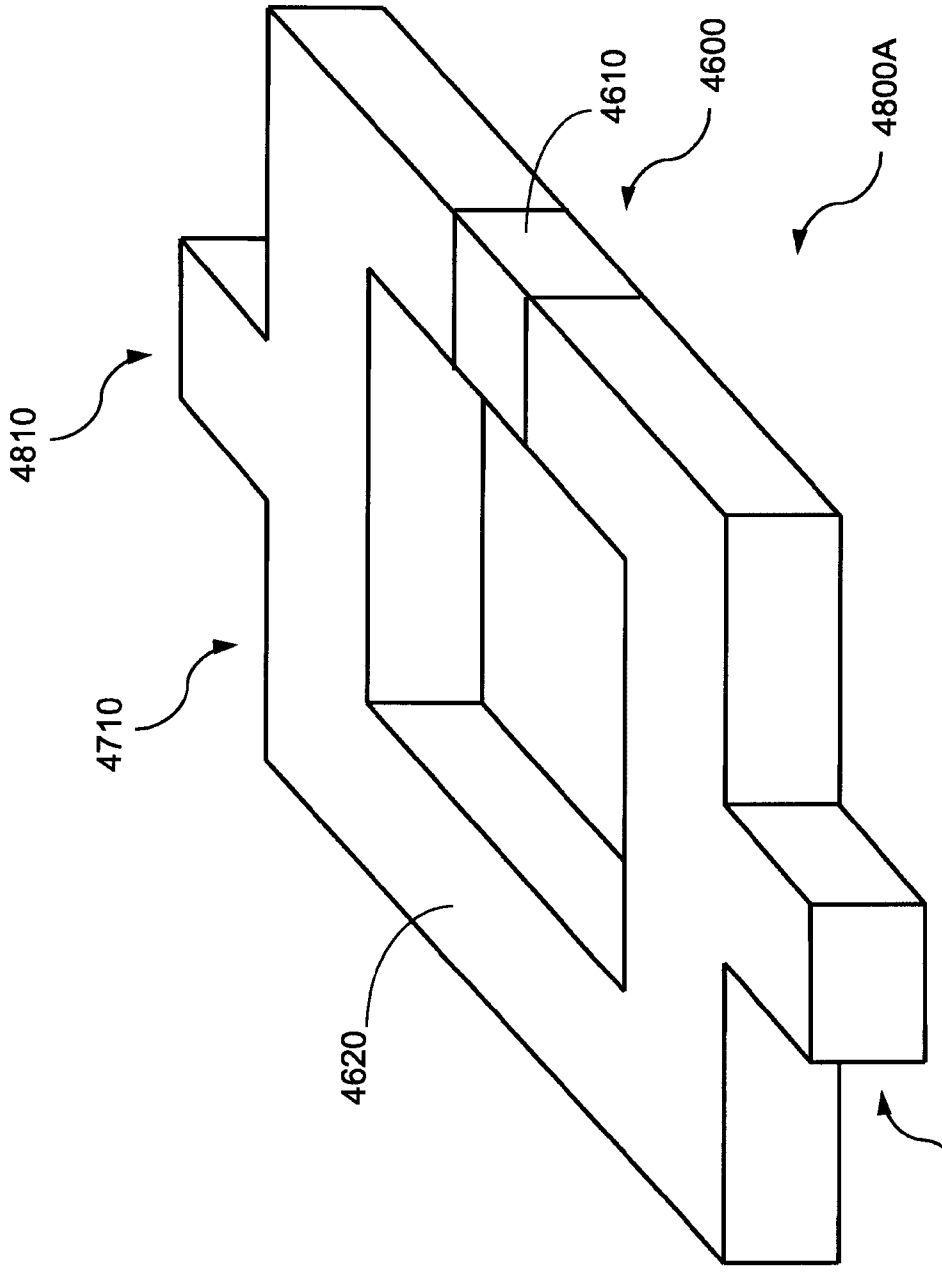


FIG. 48A-A

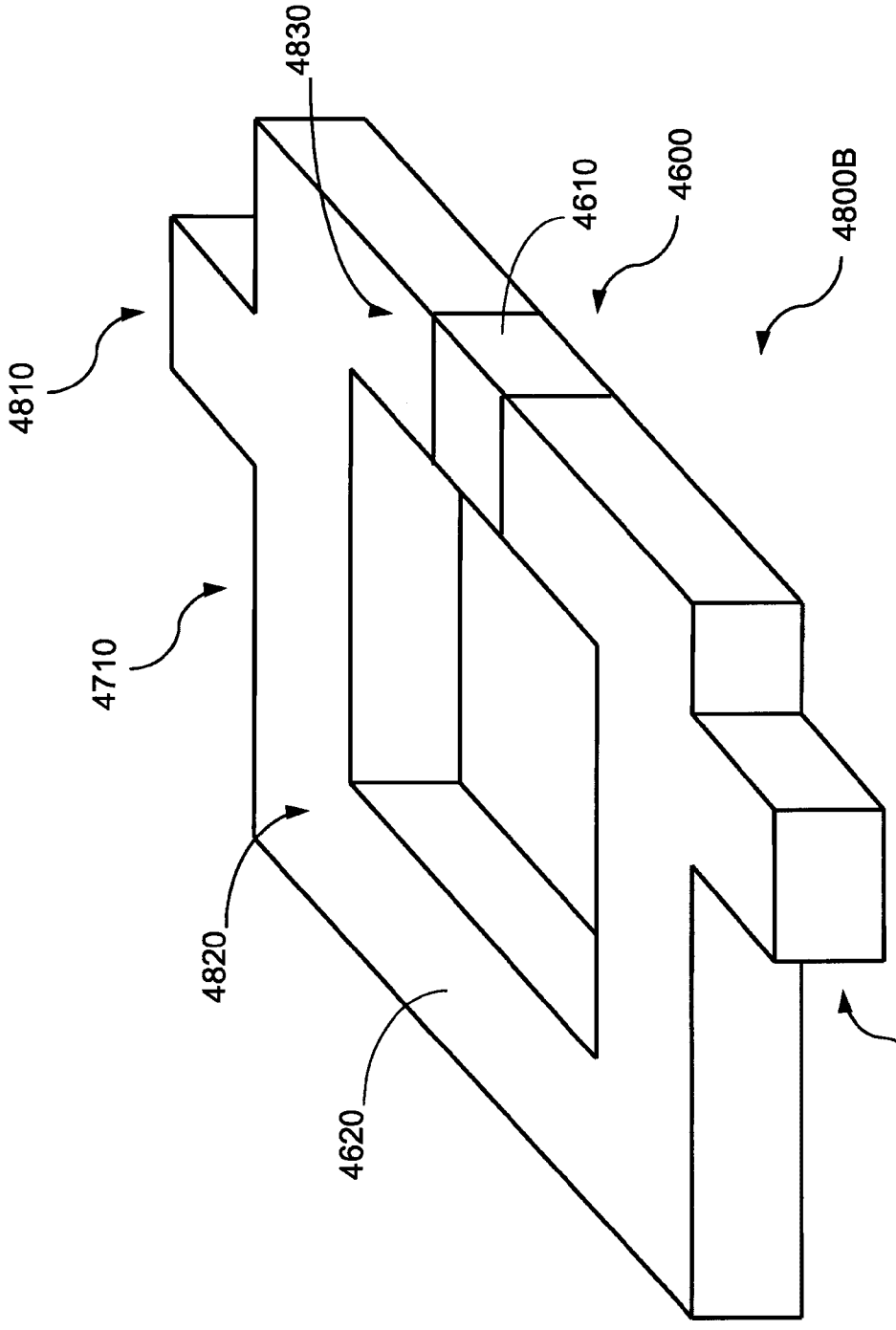


FIG. 48B-A

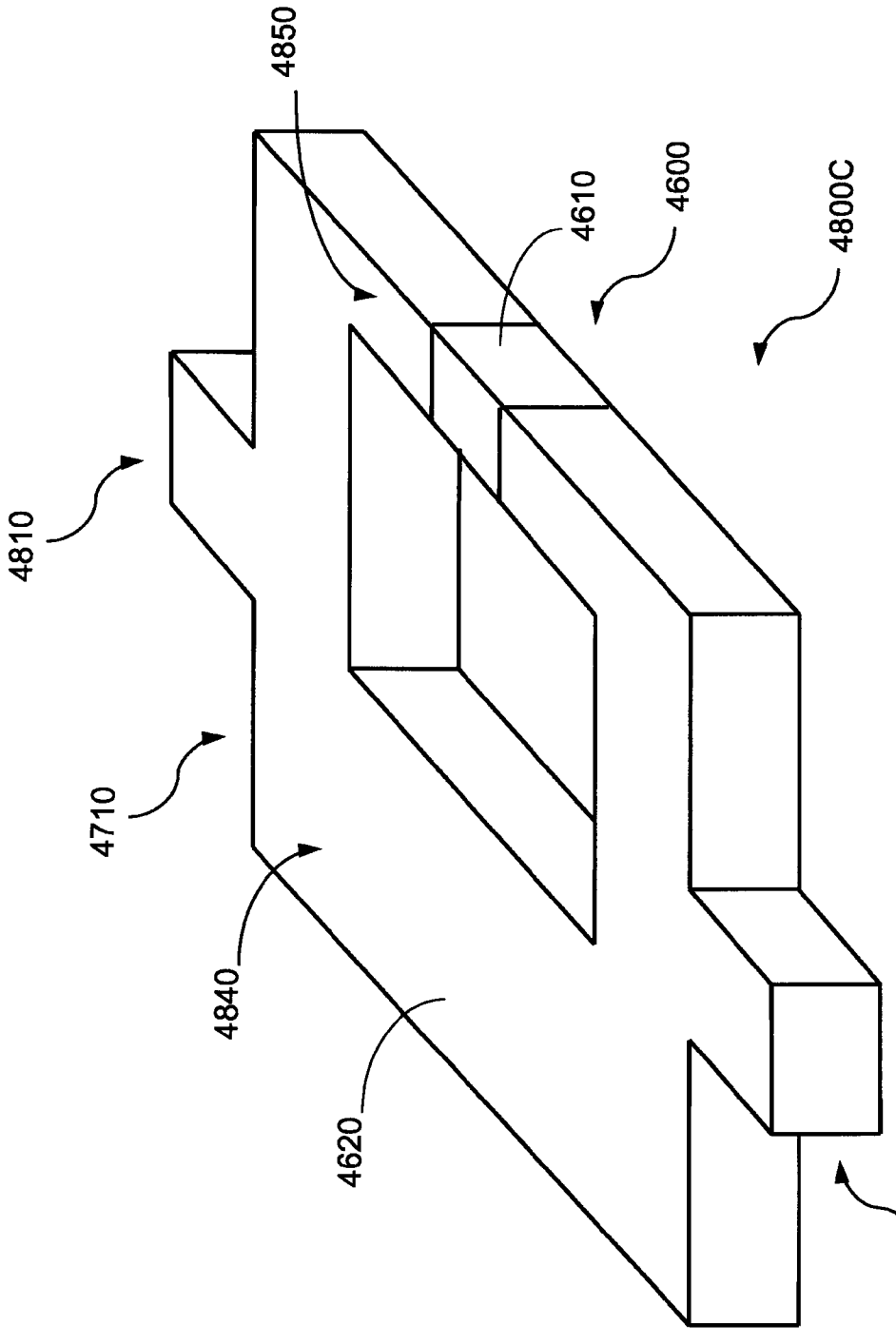


FIG. 48C-A

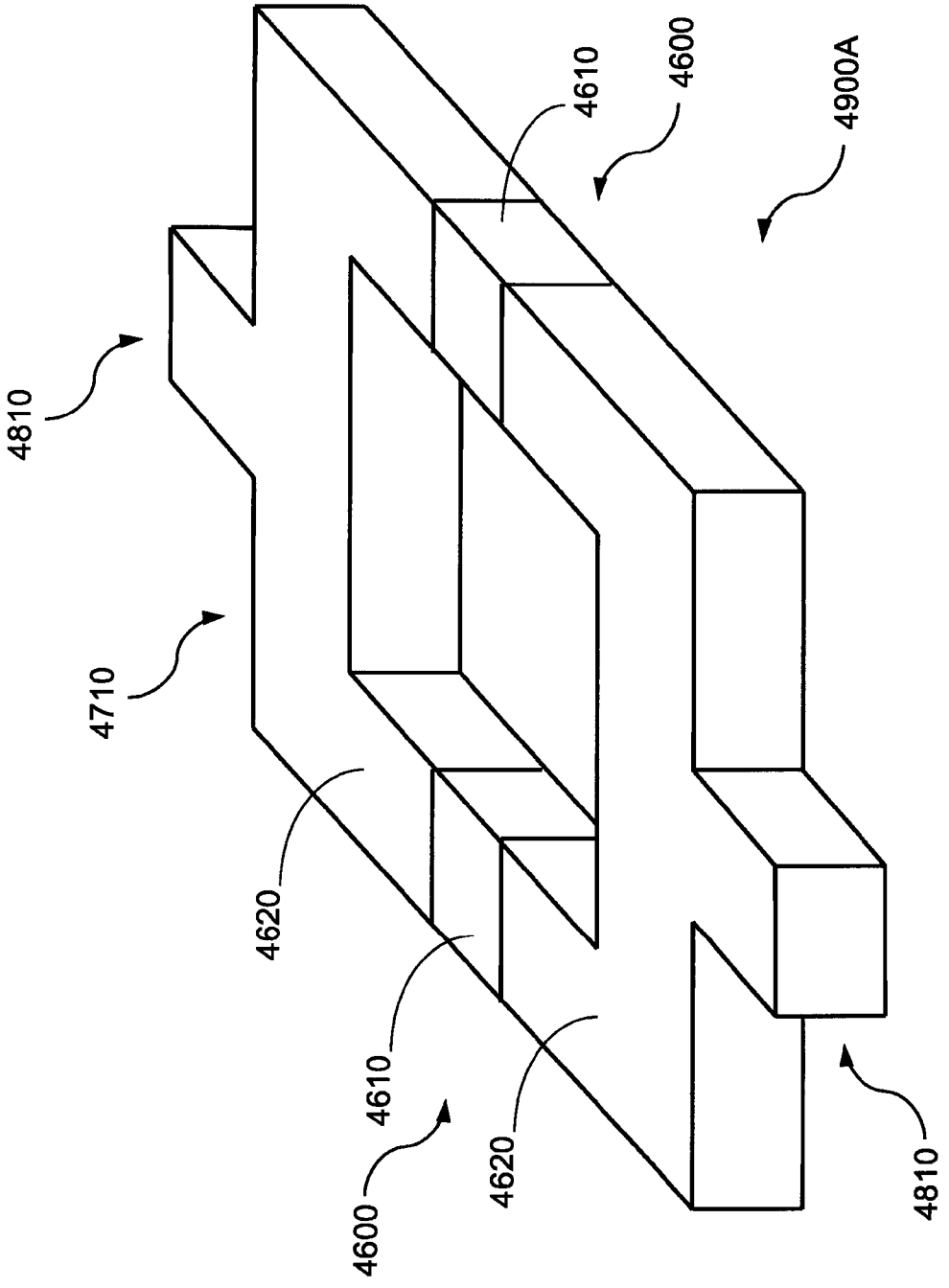


FIG. 49A-A

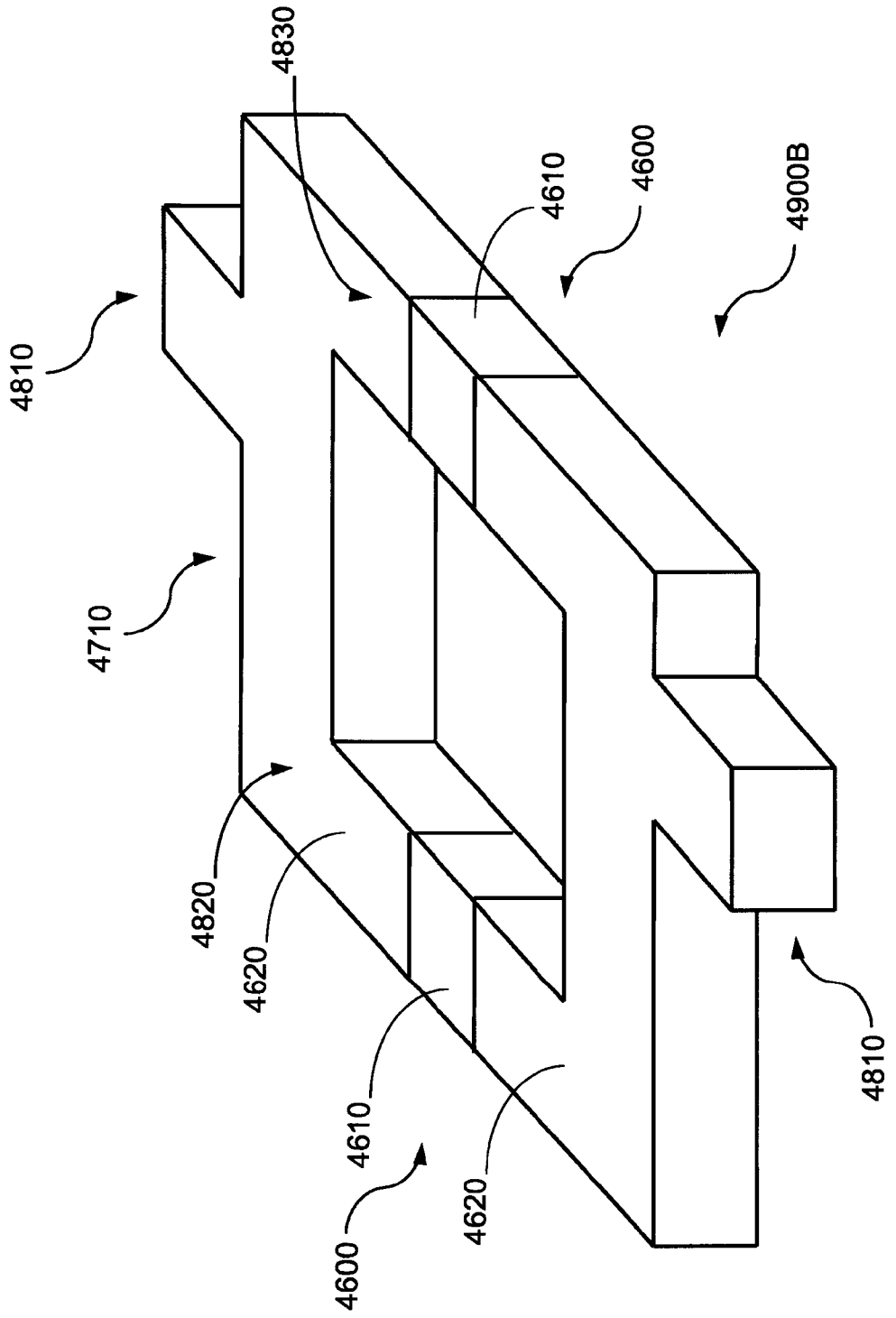


FIG. 49B-A

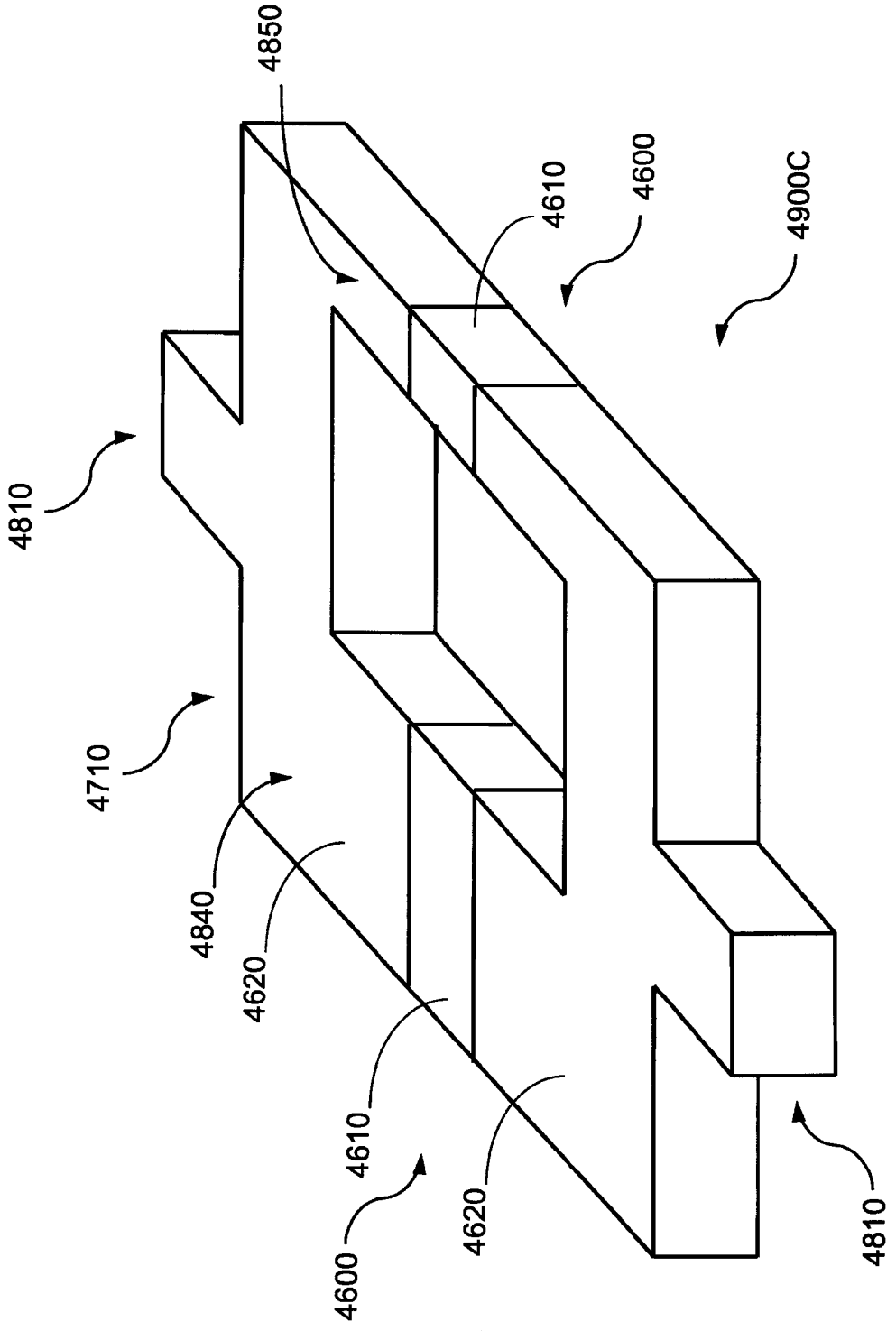


FIG. 49C-A

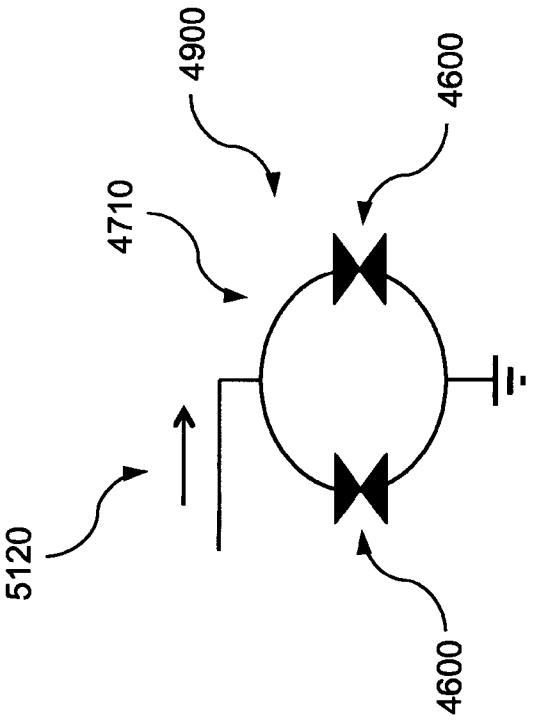


FIG. 51-A

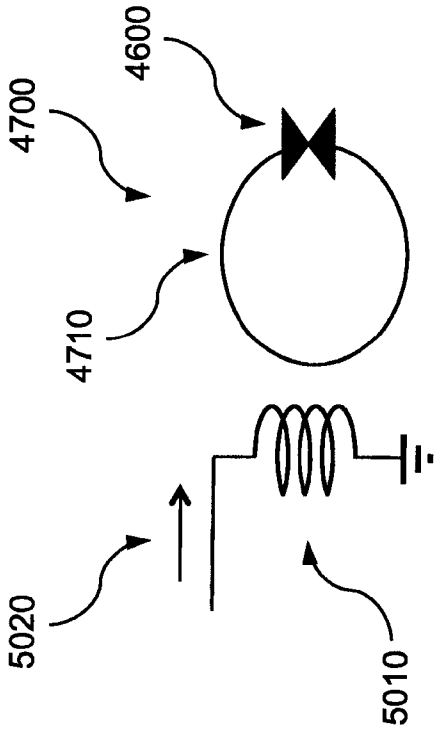


FIG. 50-A

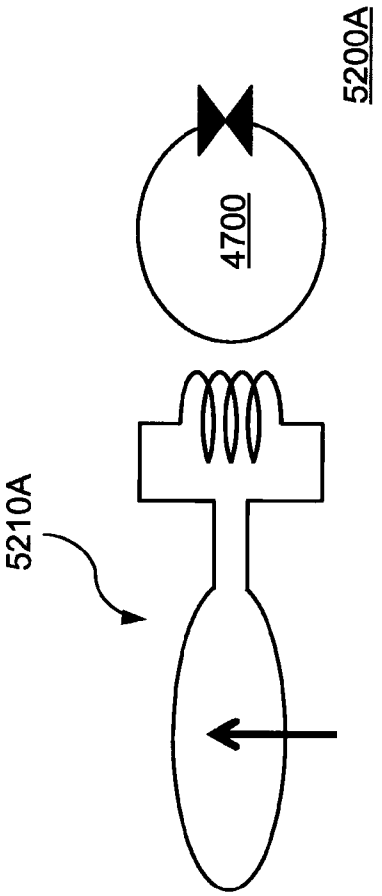


FIG. 52A-A

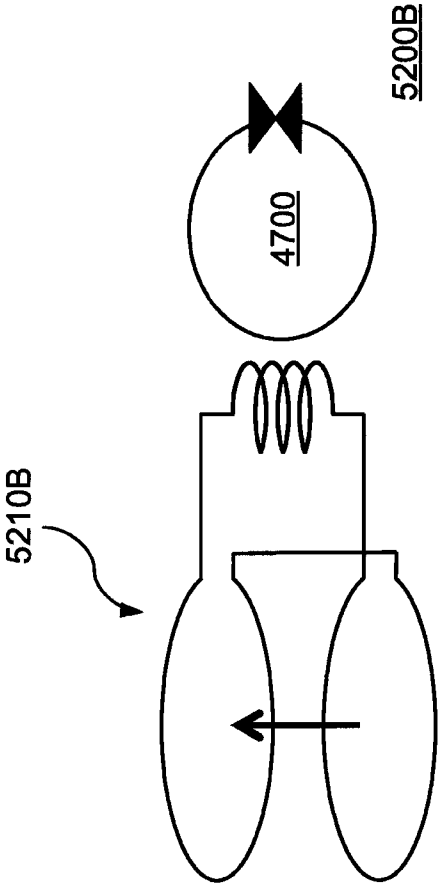
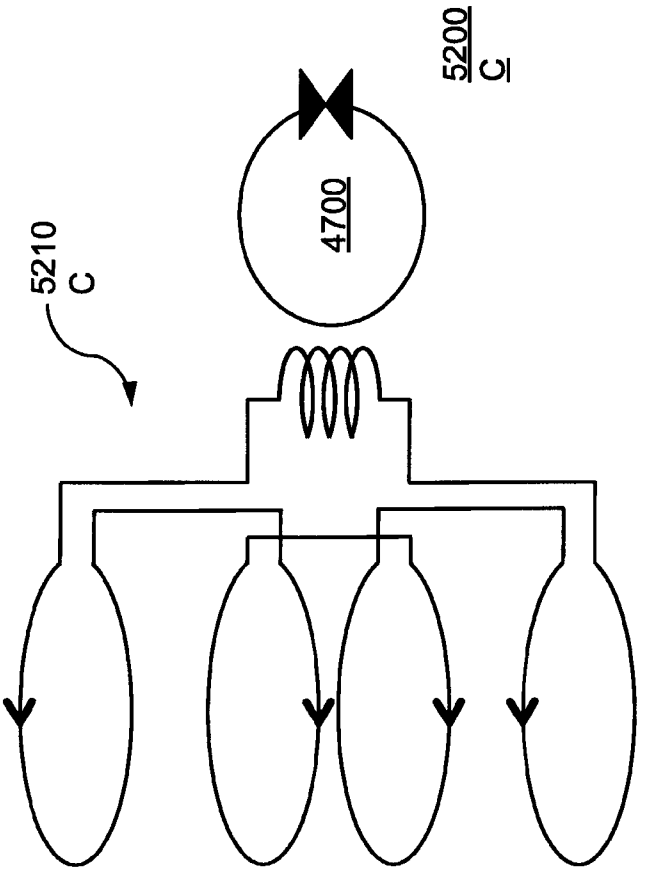


FIG. 52B-A

FIG. 52C-A



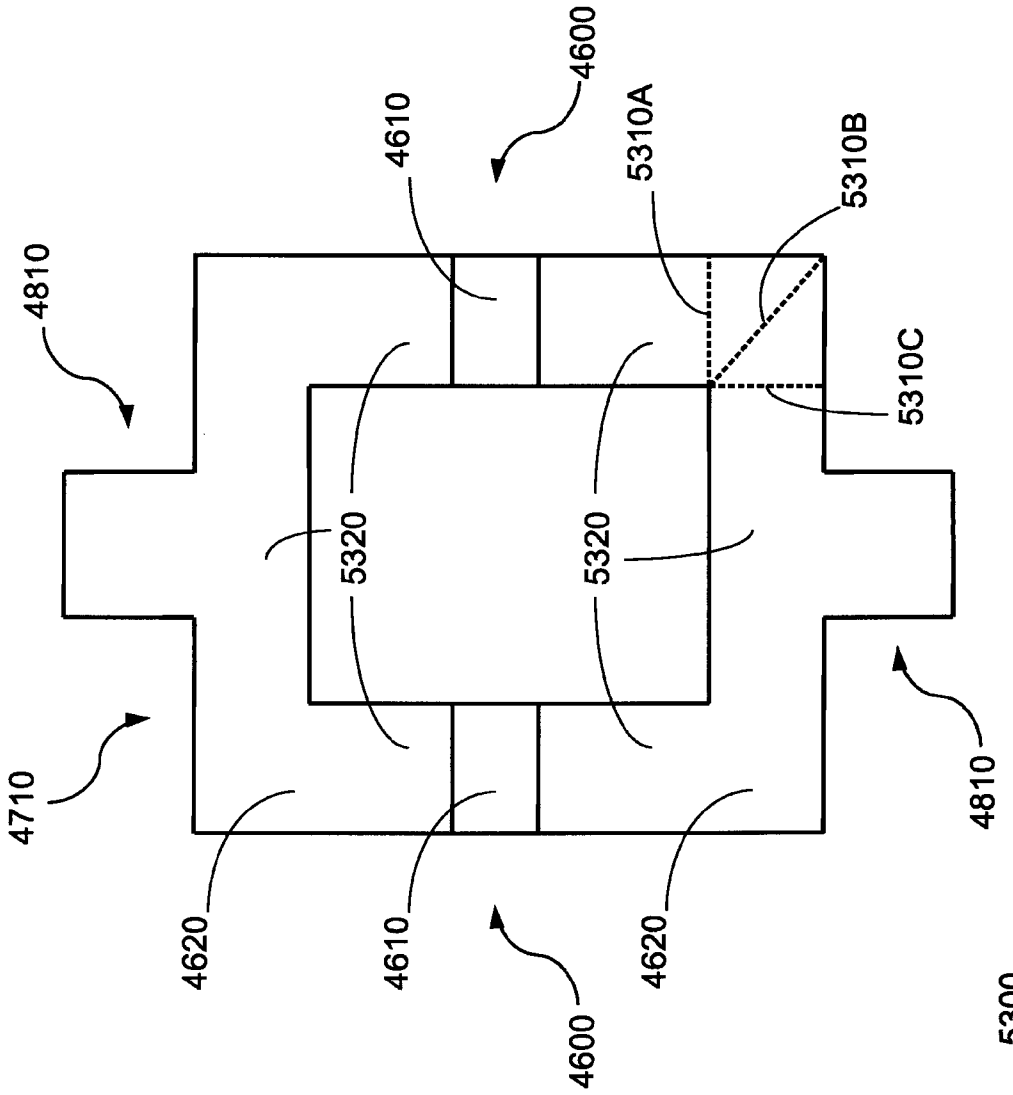

4600
4610
5310A
5310B
4810
5310C
5320
5320
4710
4810
4620
4610
4620
4600
5300

FIG. 53-A

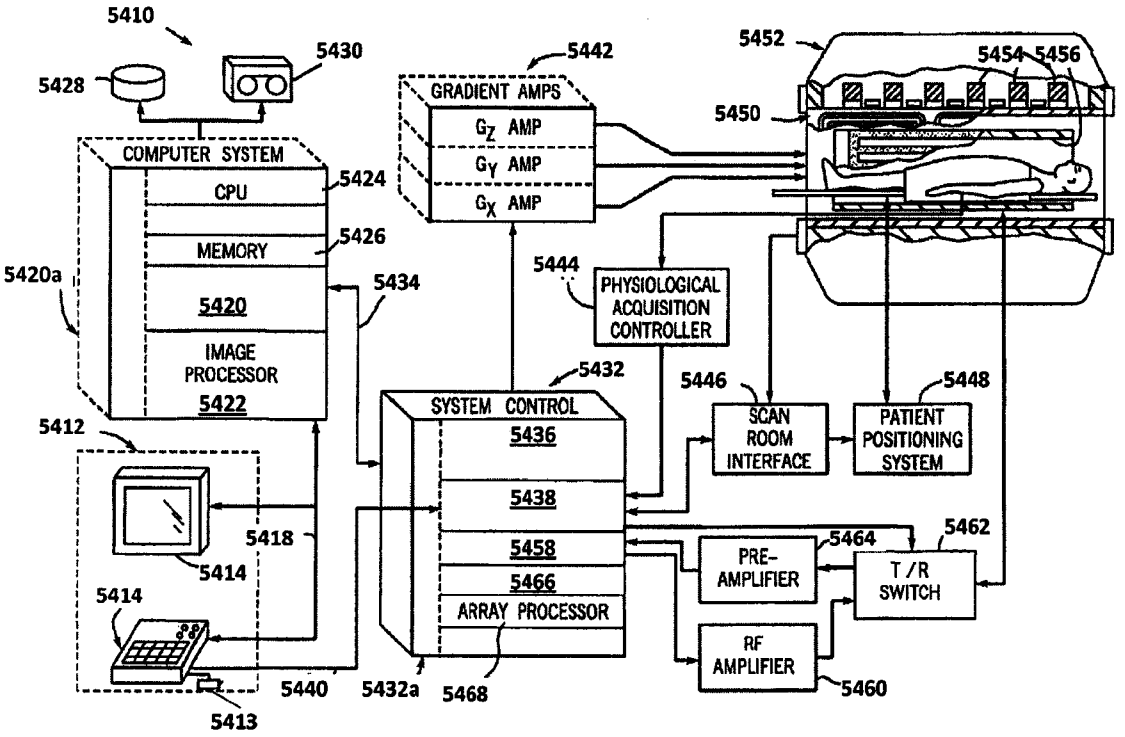

5410
5430
5428
COMPUTER SYSTEM
CPU
5424
MEMORY
5426
5420a
5420
5434
IMAGE PROCESSOR
5422
5412
5418
5414
5414
5413
5440
5432a
5468
5442
GRADIENT AMPS
G_Z AMP
G_Y AMP
G_X AMP
5444
PHYSIOLOGICAL ACQUISITION CONTROLLER
5432
SYSTEM CONTROL
5436
5438
5458
5466
ARRAY PROCESSOR
5452
5454
5456
5450
5446
SCAN ROOM INTERFACE
5448
PATIENT POSITIONING SYSTEM
5462
5464
PRE-AMPLIFIER
T/R SWITCH
RF AMPLIFIER
5460

Figure 54-A

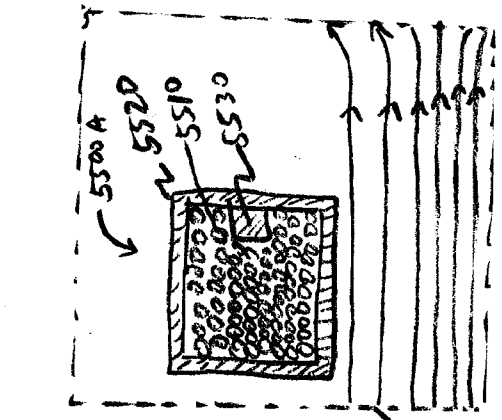


Figure 55C-A

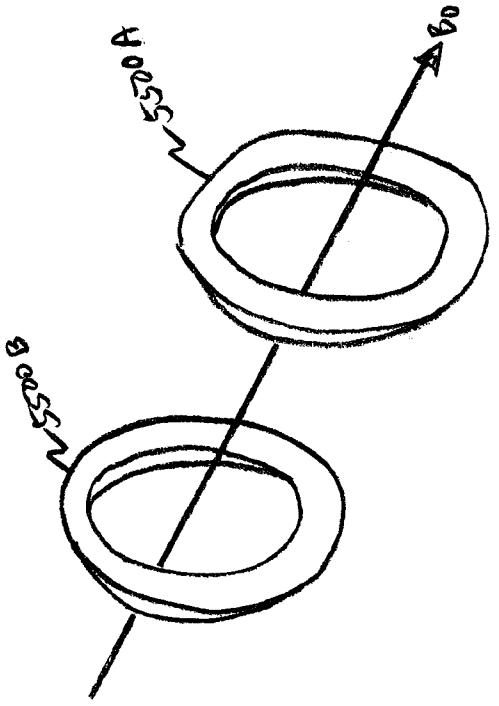


Figure 55A-A

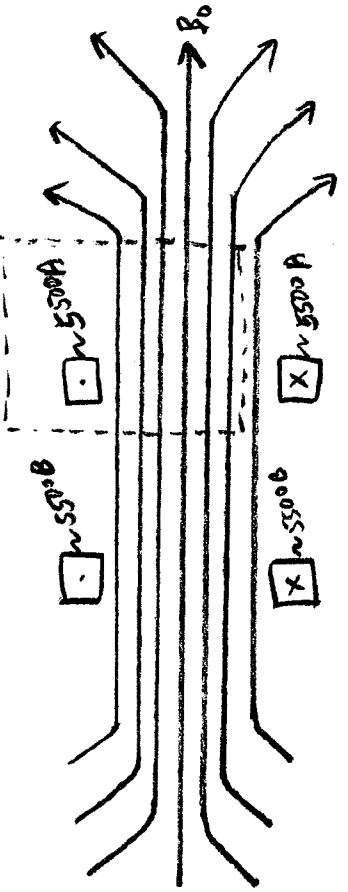


Figure 55B-A

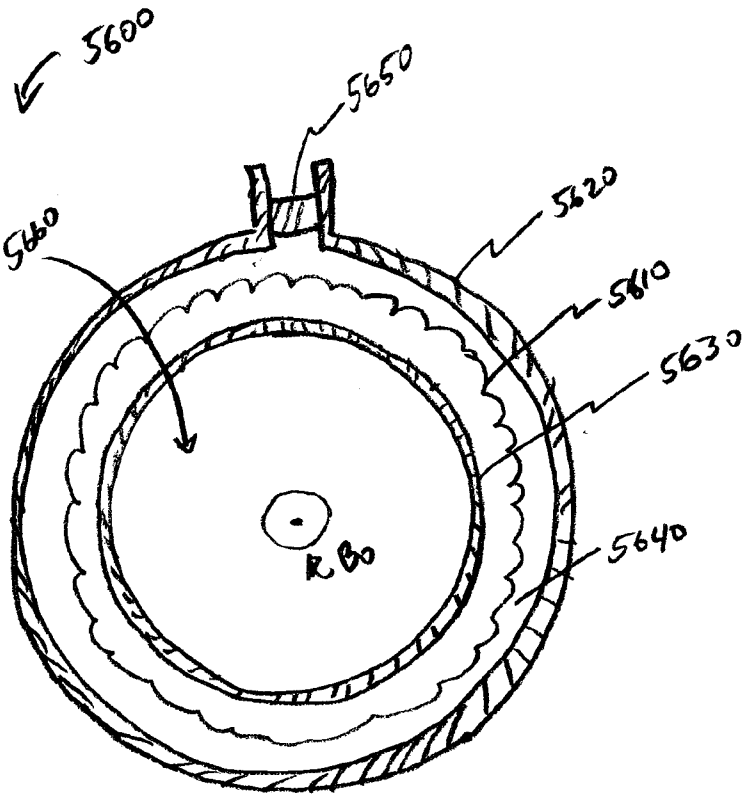


Figure 56-A

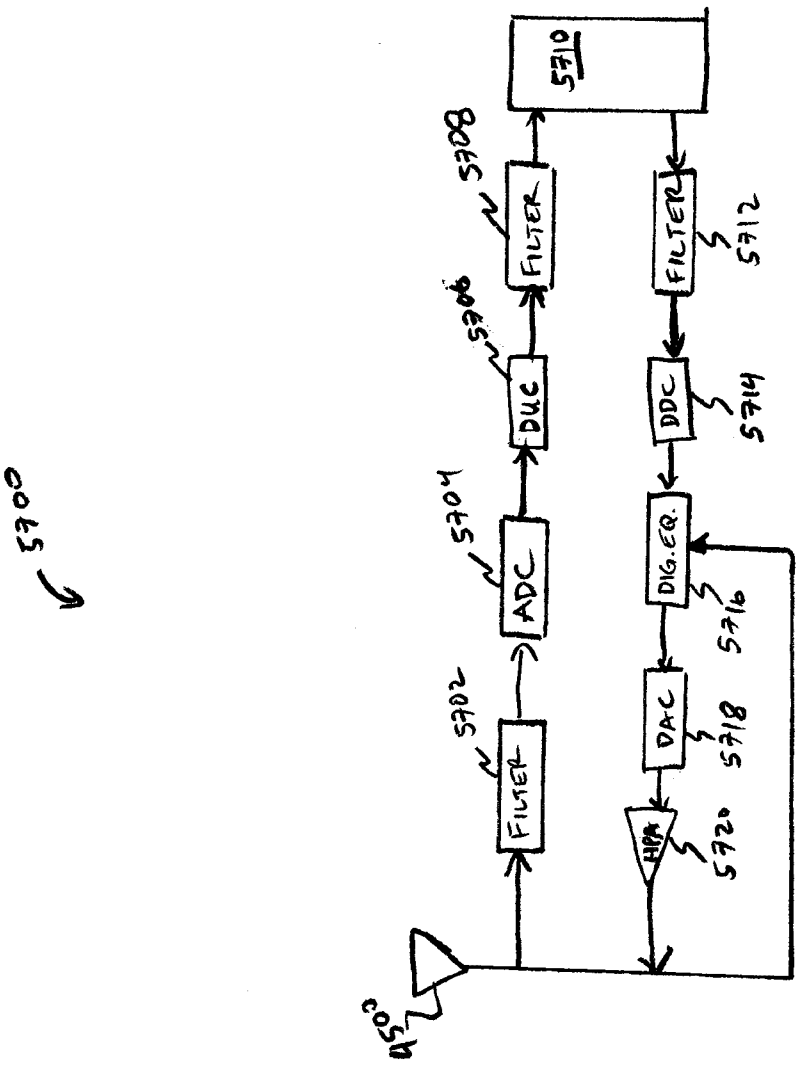

5700
5702
FILTER
5704
ADC
5706
DUC
5708
FILTER
5710
5712
FILTER
5714
DDC
5716
DIG. EQ.
5718
DAC
5720
PA
DUPLEXER

Figure 57-A

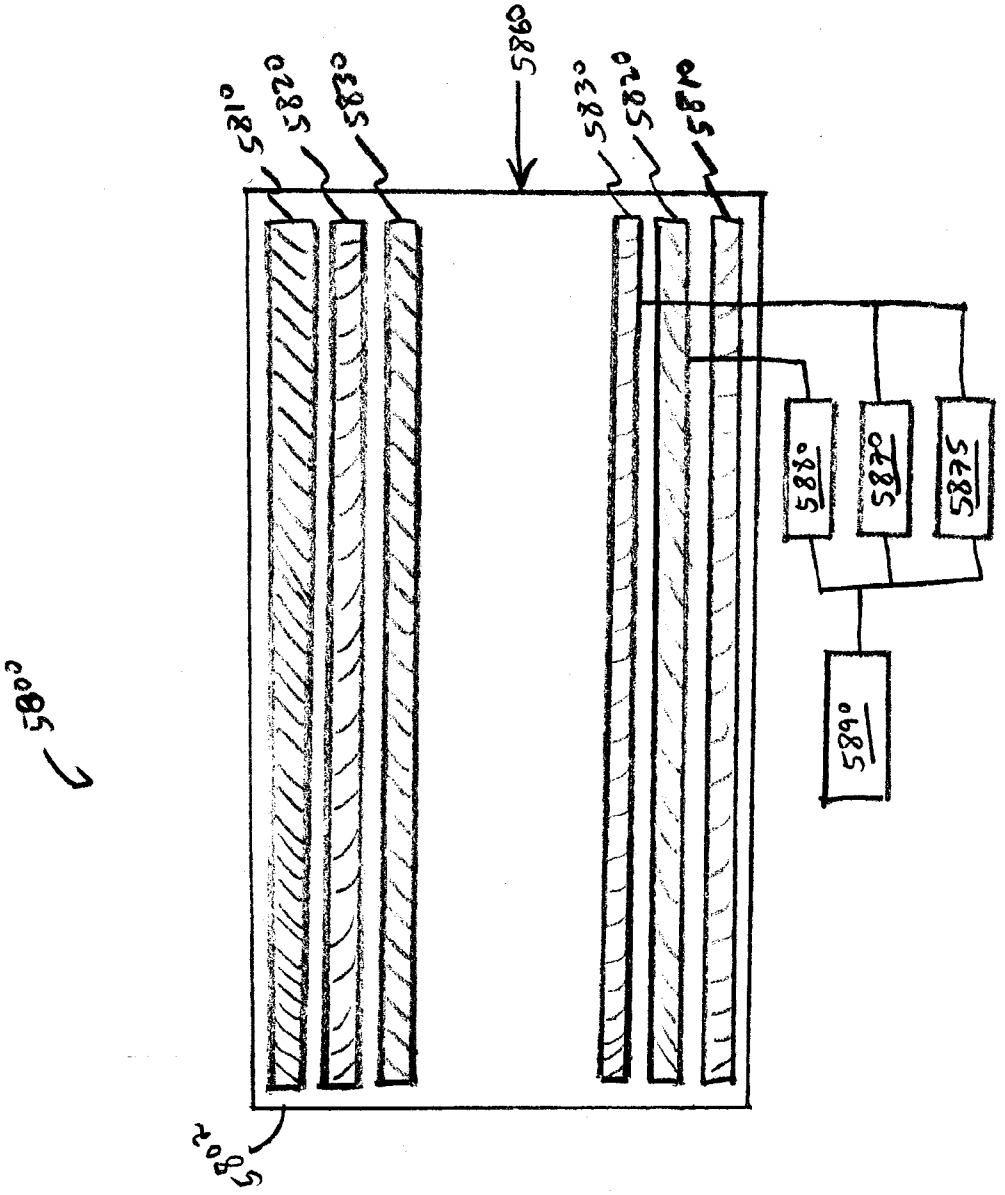


Figure 58-A

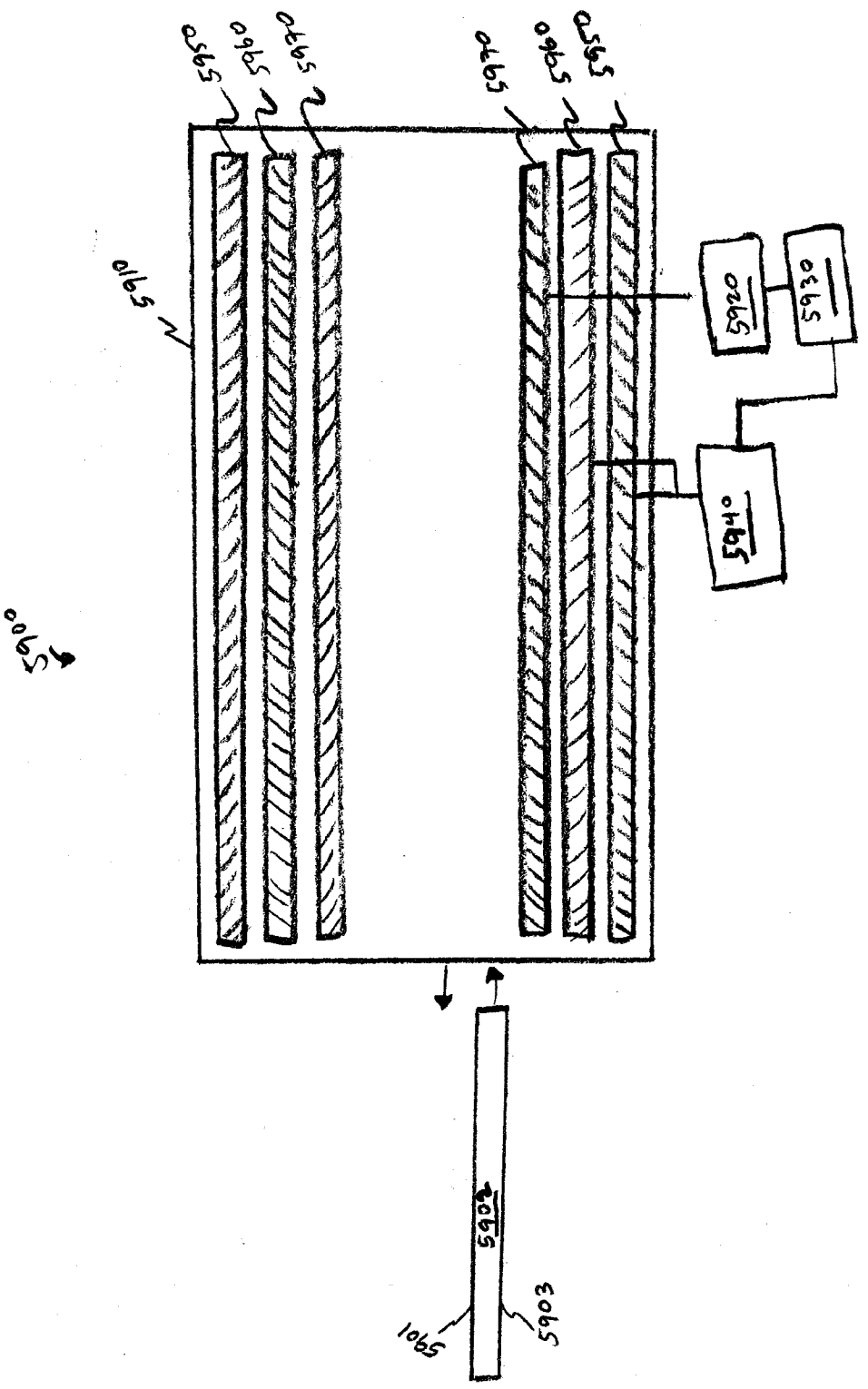


Figure 59-A

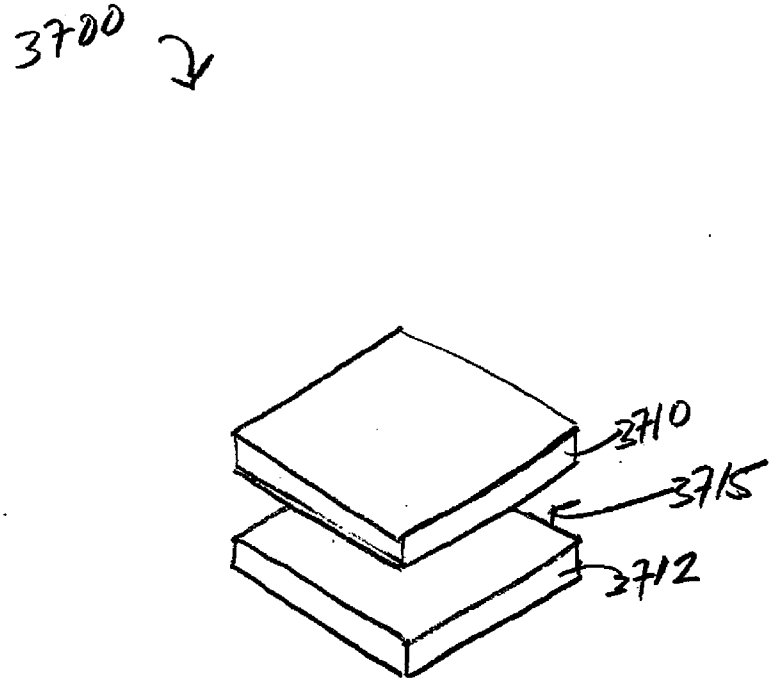


Fig 37A-B

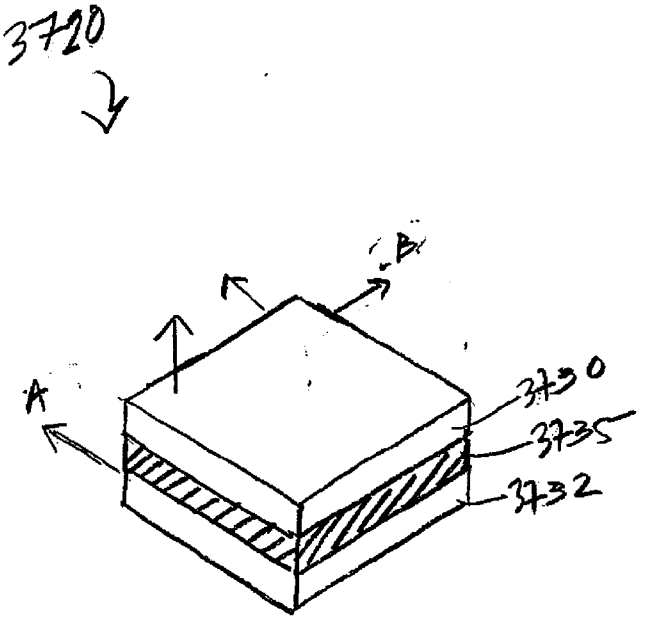


Fig. 37B-B

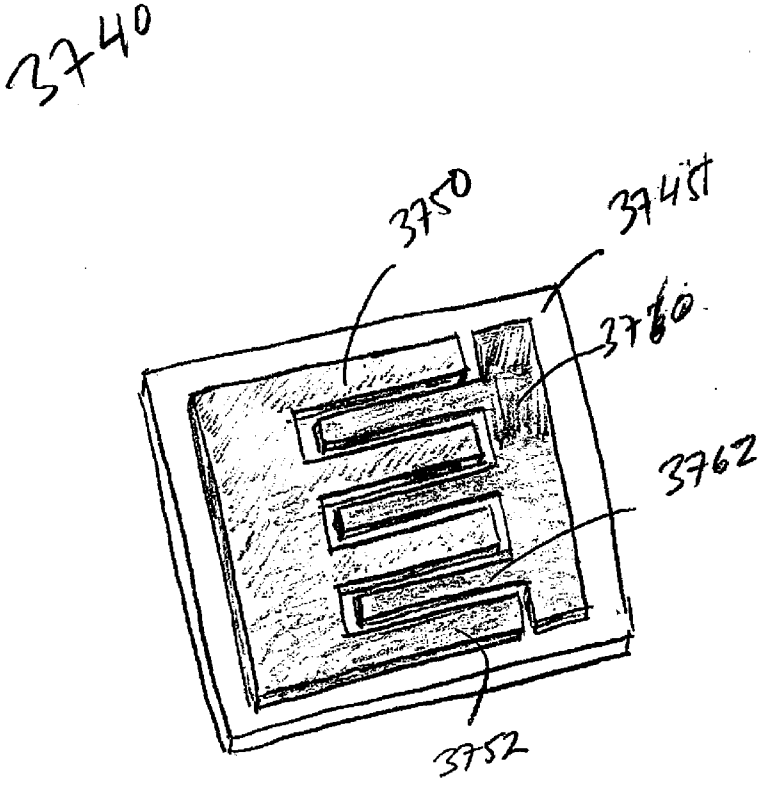


Fig 37C-B

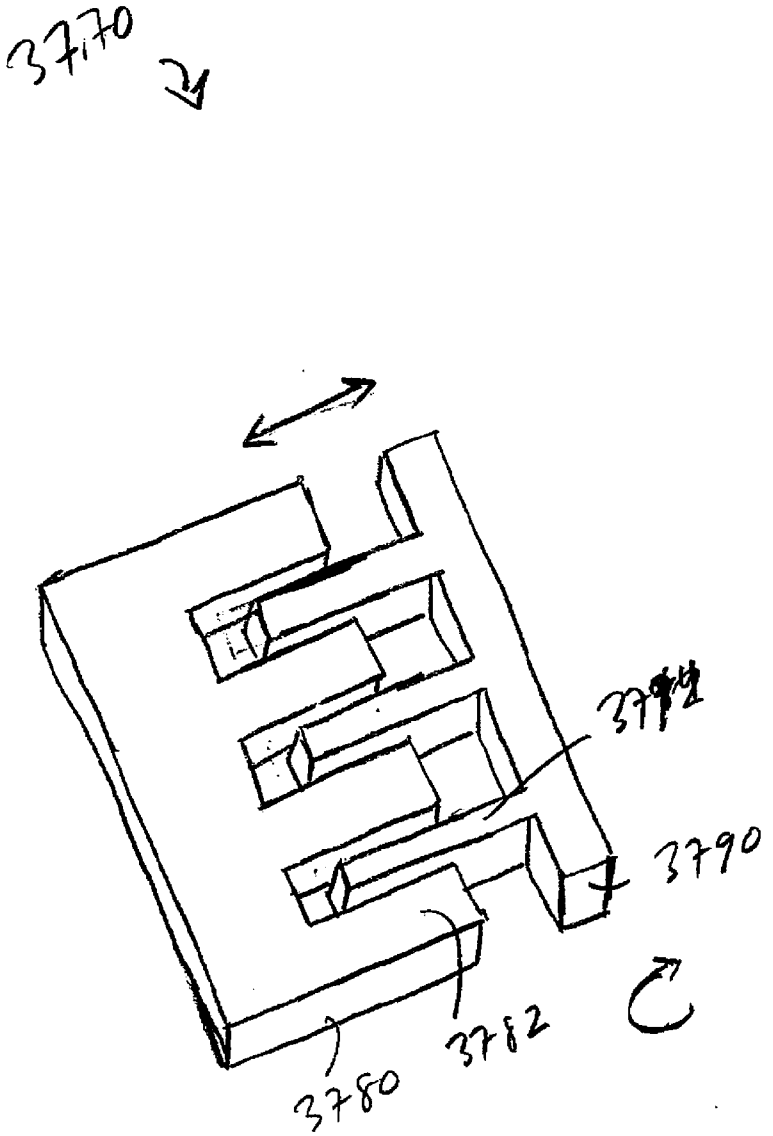


Fig 37D-B

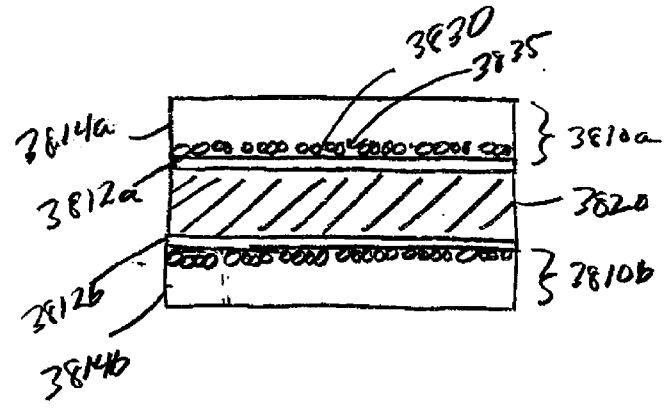


Fig 38A-B

38B

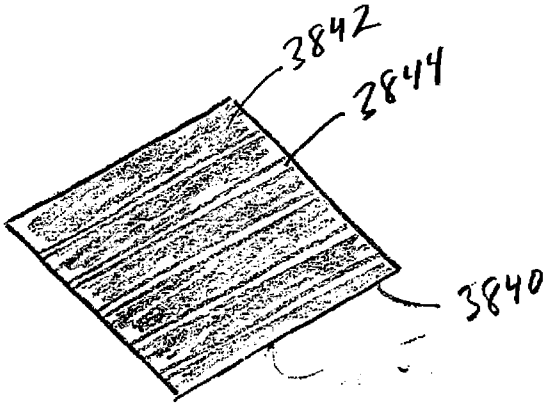


Fig 38B-B

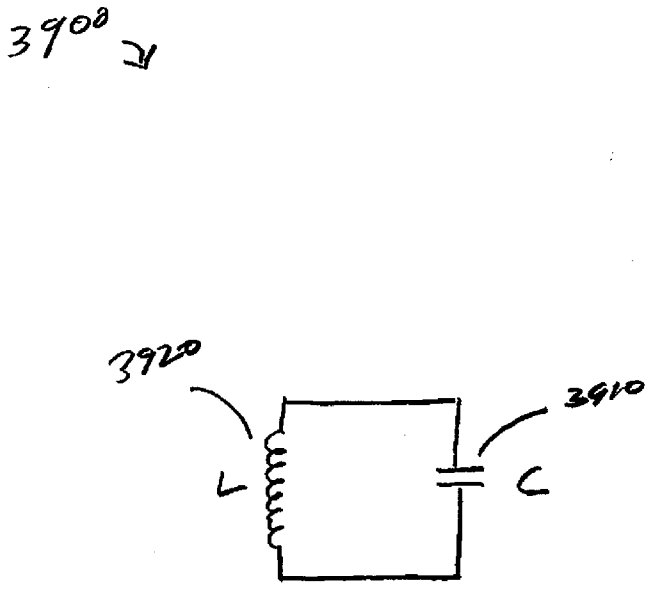


Fig 39-B

4000

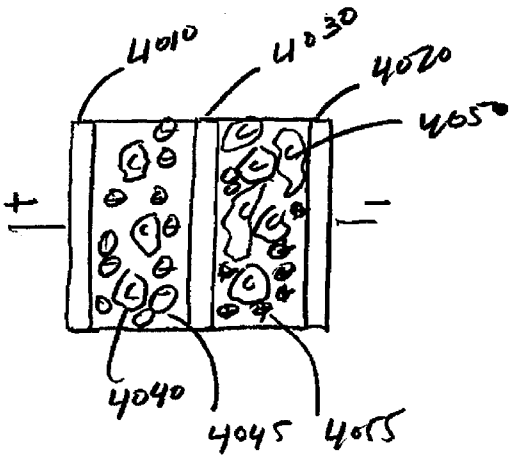


Fig 40-B

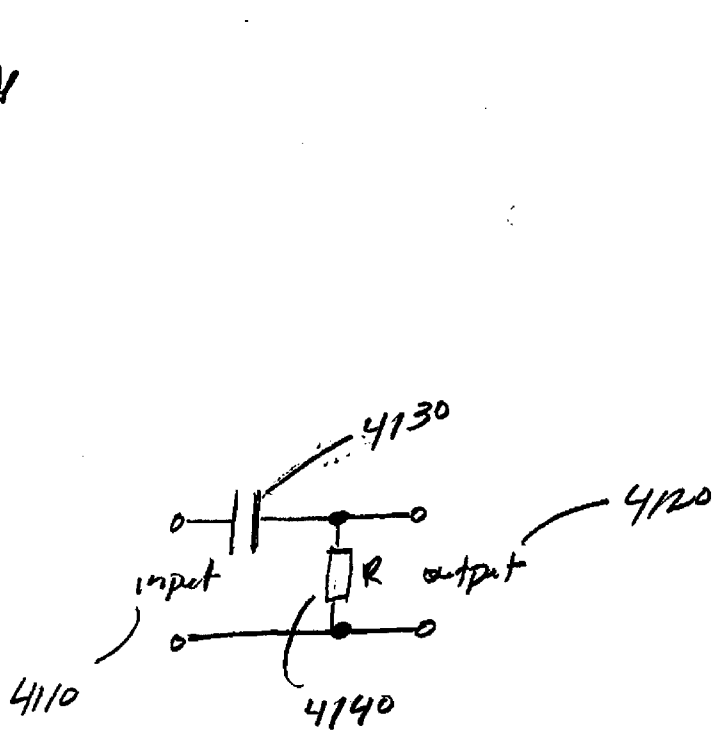


Fig 41-B

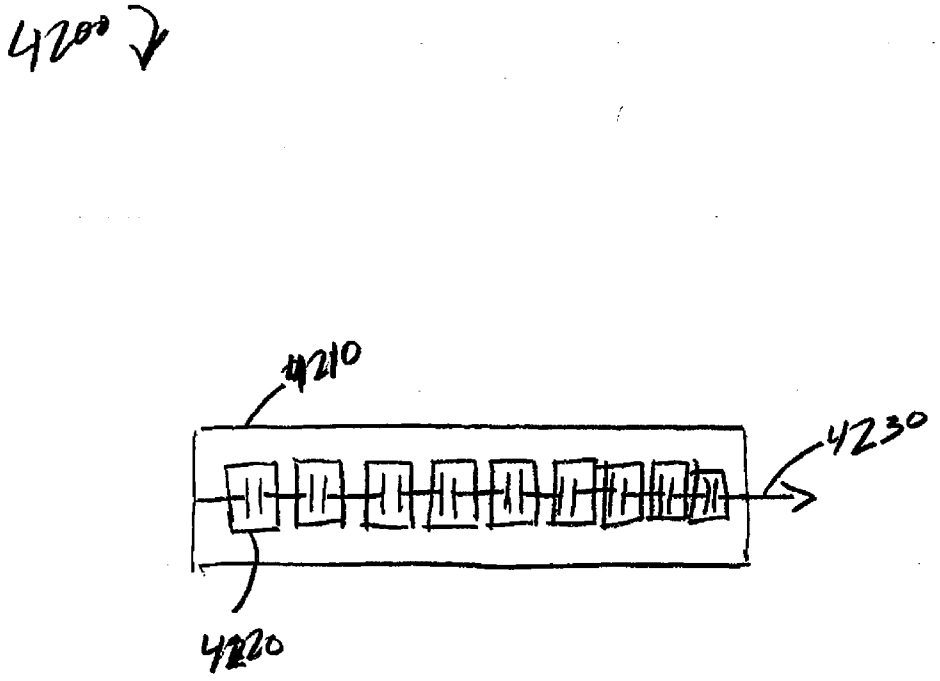


Figure 42-B

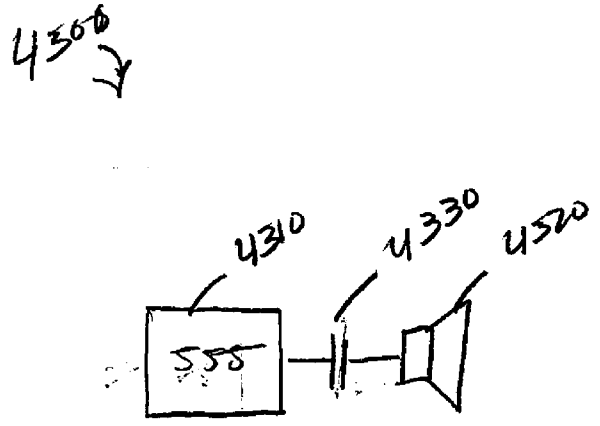


Fig 43-B

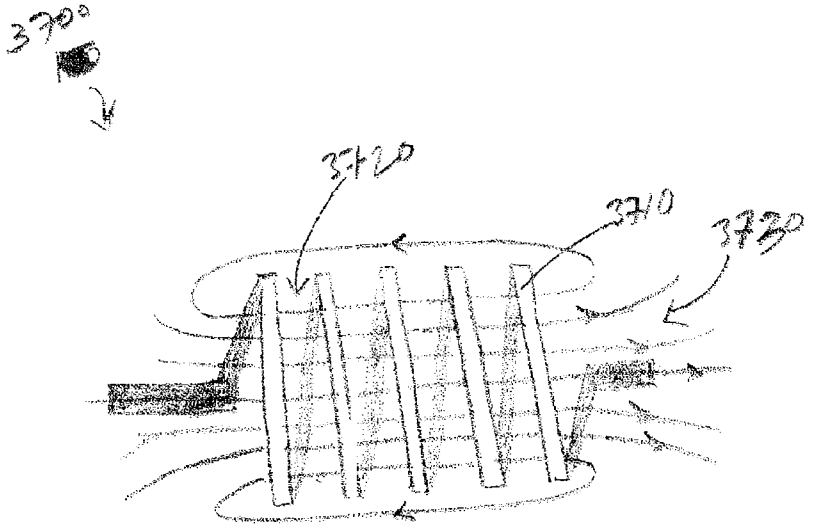


Fig 37-C

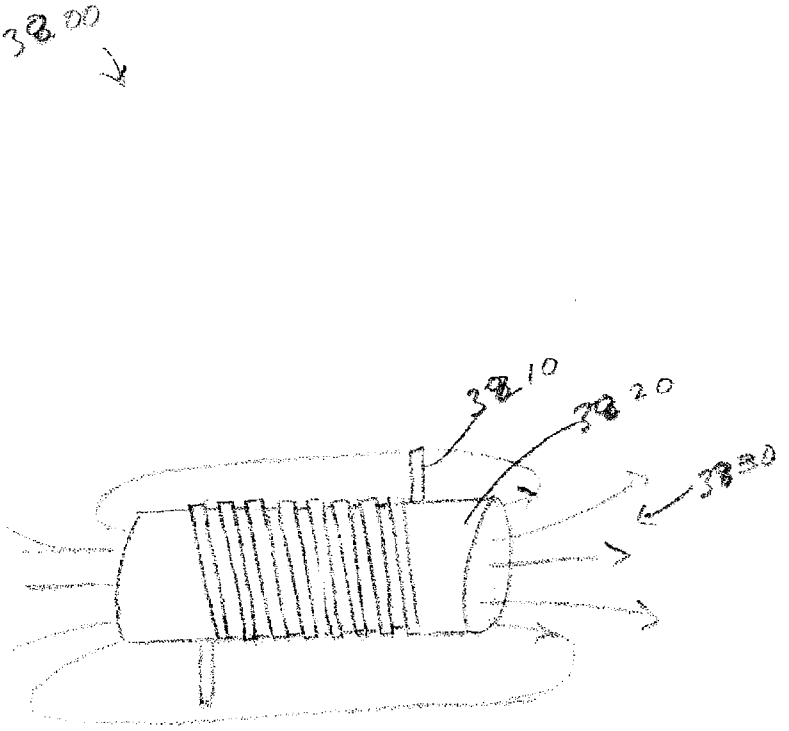


Fig 38-C

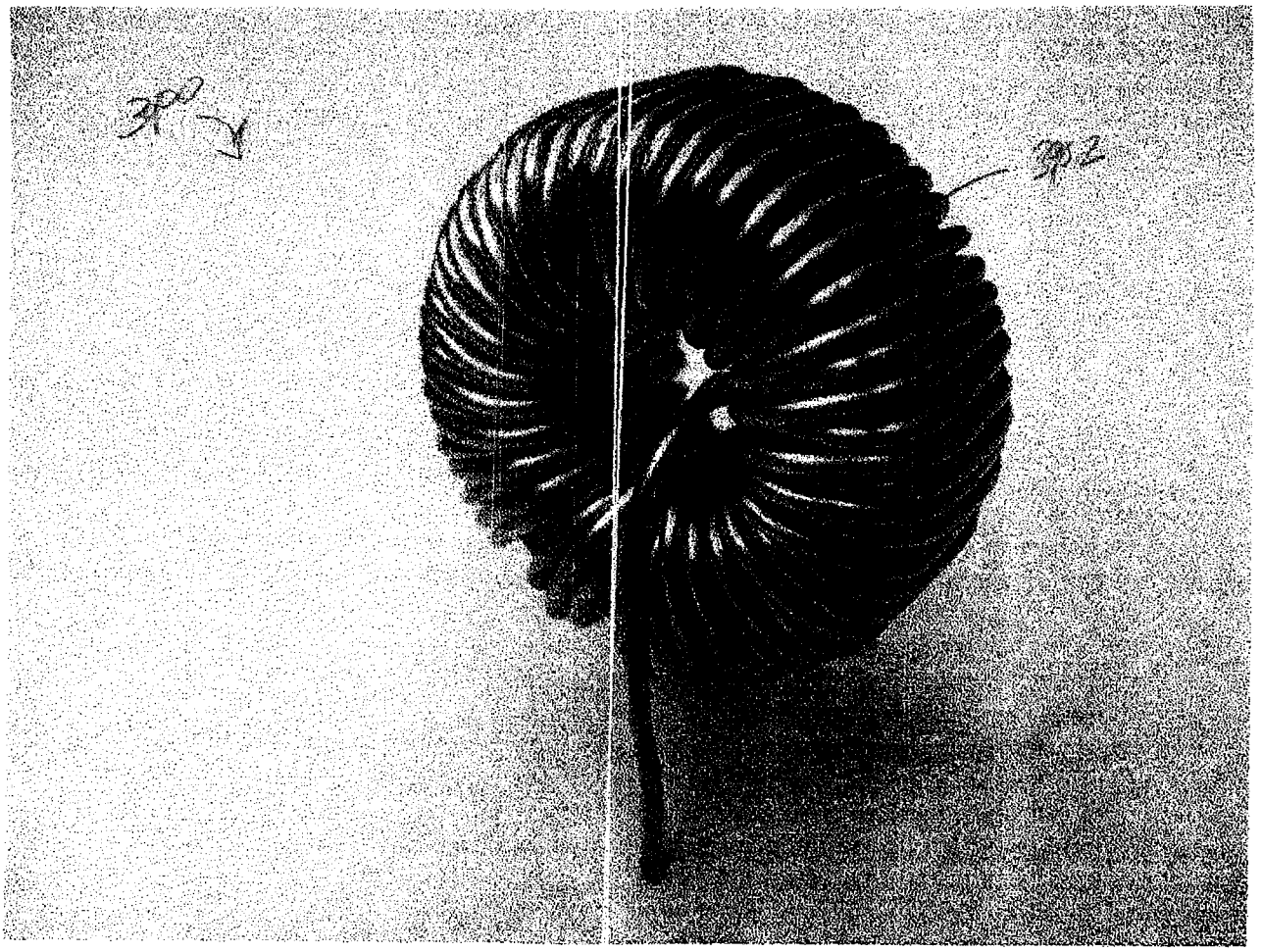


Fig 39A-C

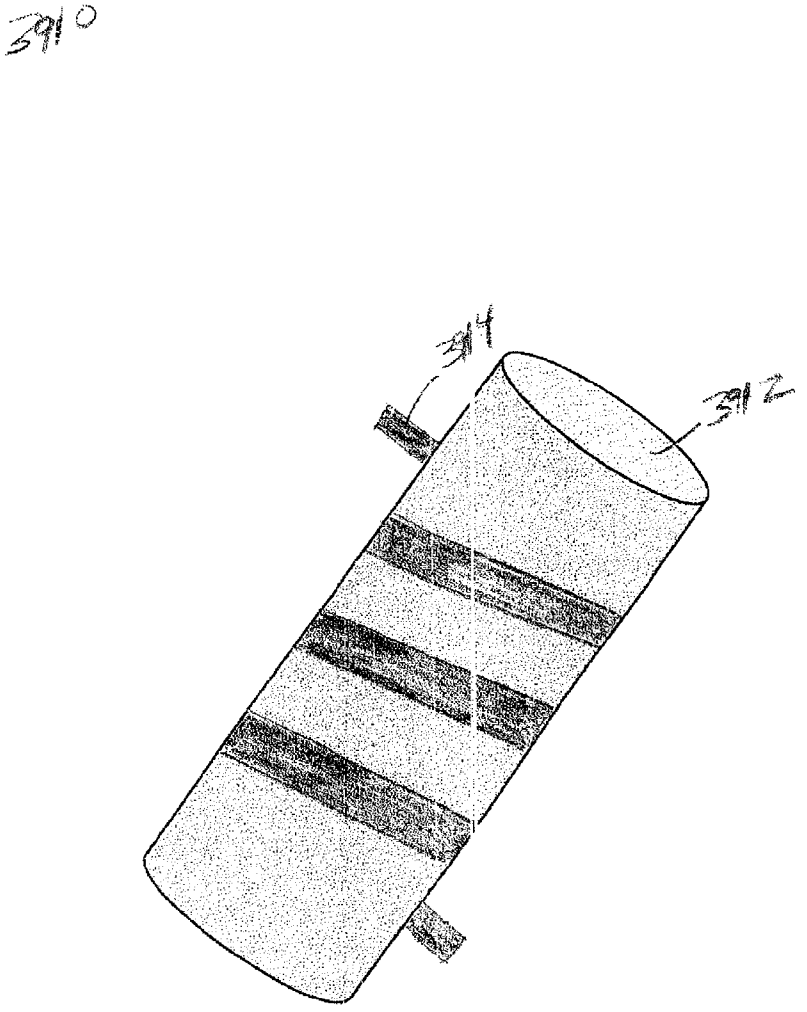


Fig 39B-C

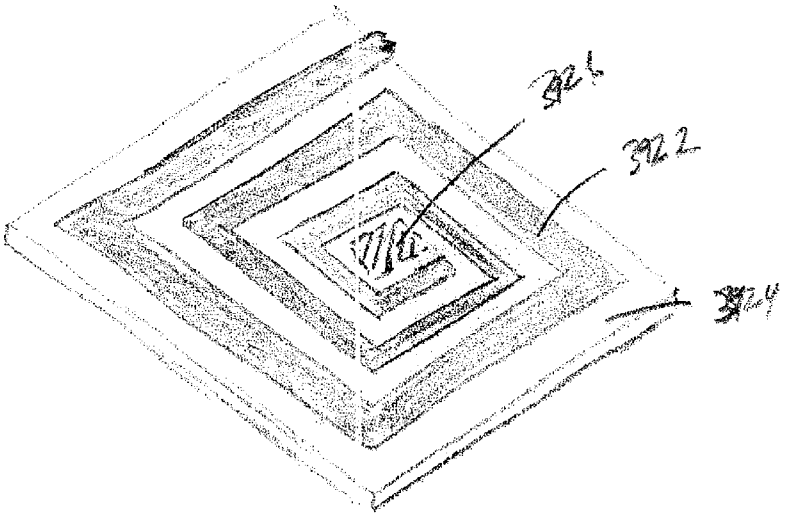


Fig 39C-C

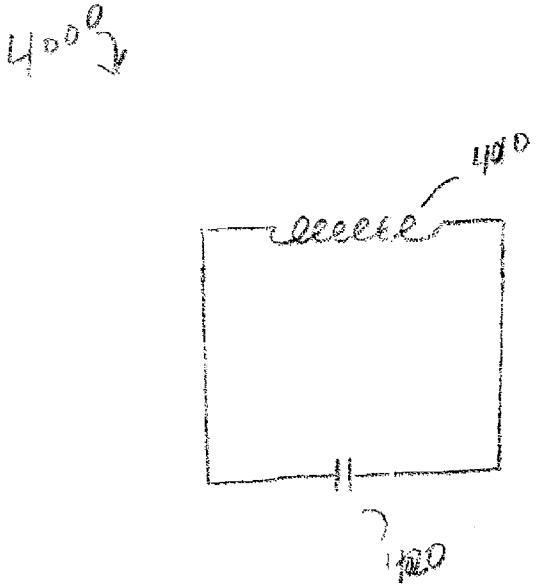


Fig 40-C

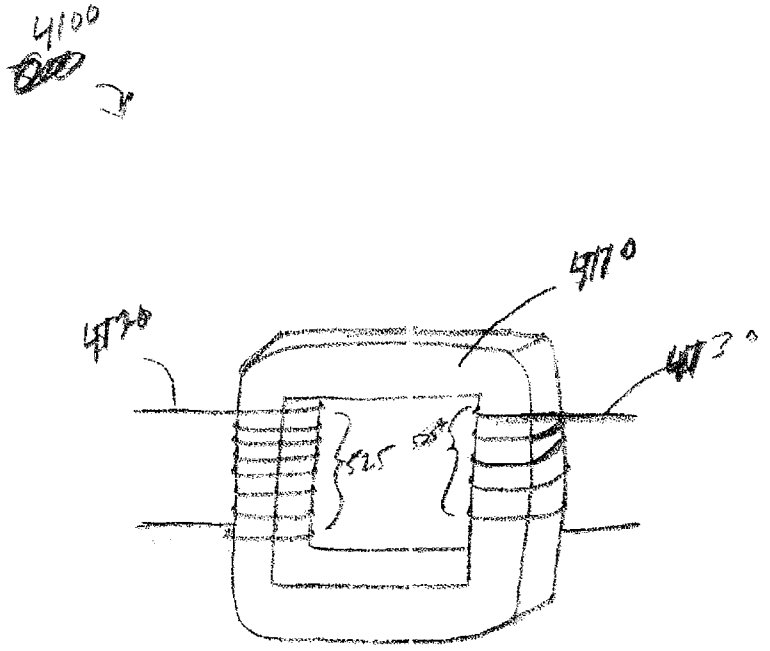


Fig 41-C

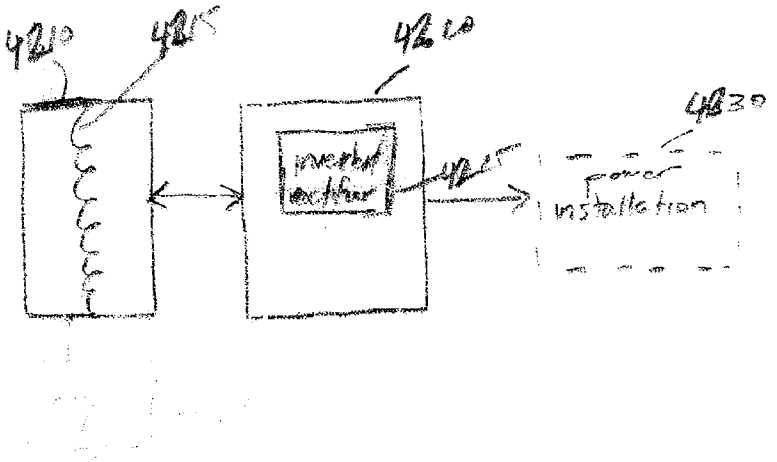

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inverter/rectifier
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power installation

Fig 42-C

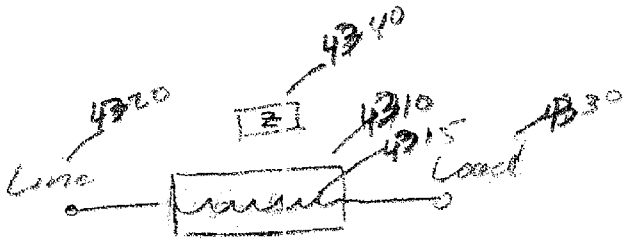


Fig 43-C



Fig 37-D

Fig. 4-D

Fig. 4-C

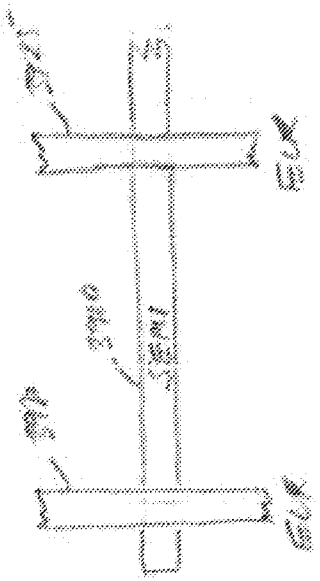


Fig. 37-D

Fig. 37-C

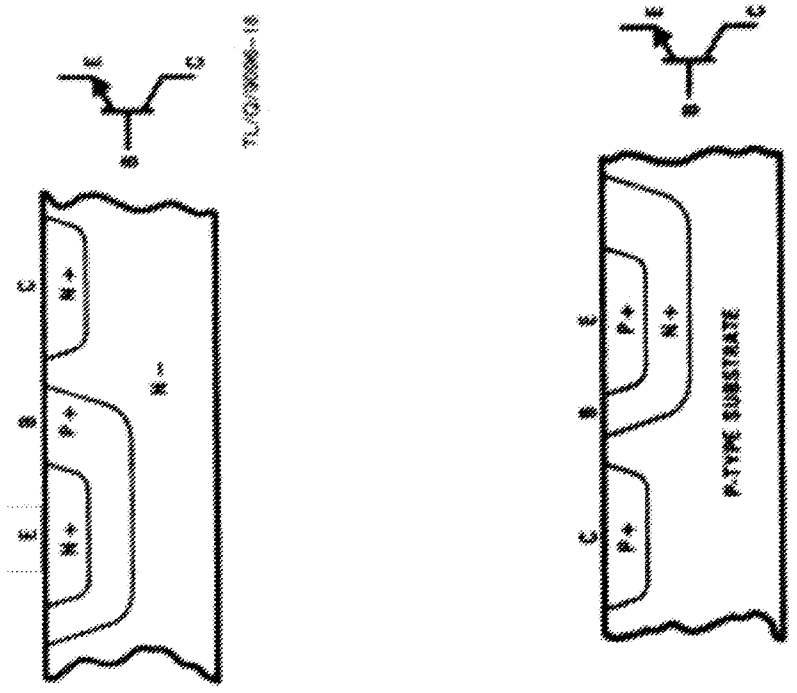


Figure 40-D

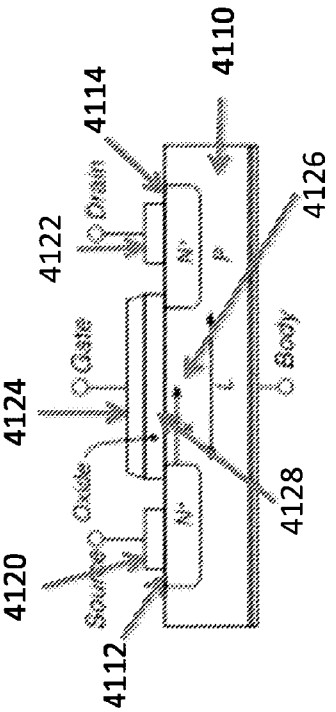
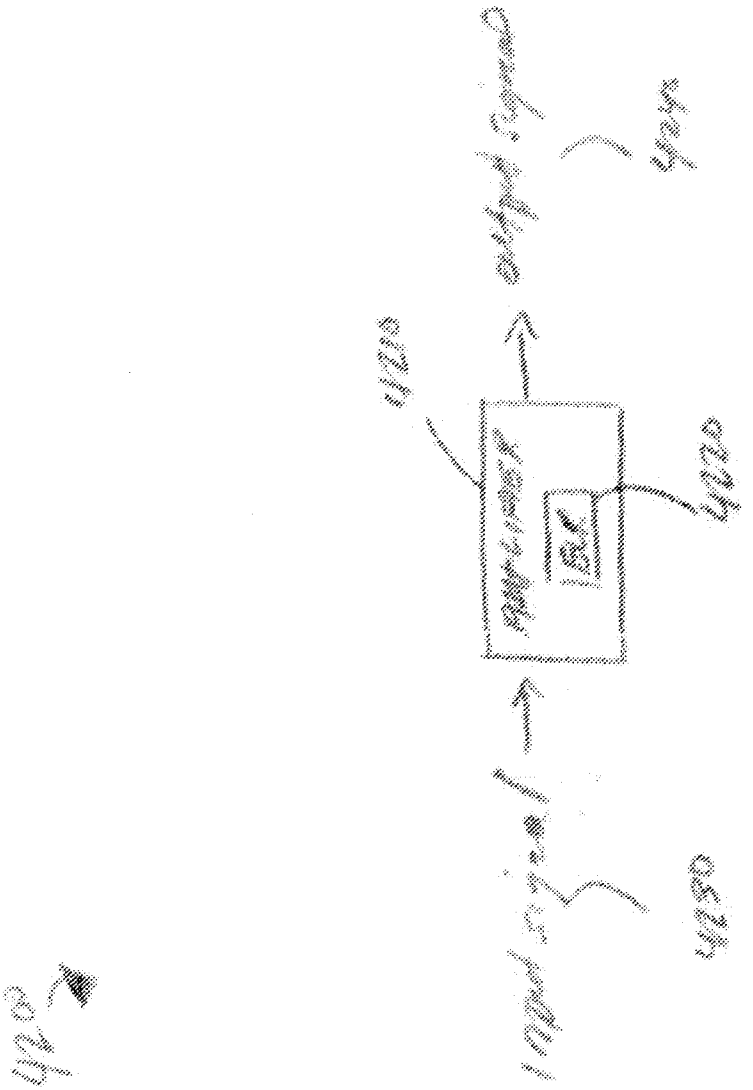
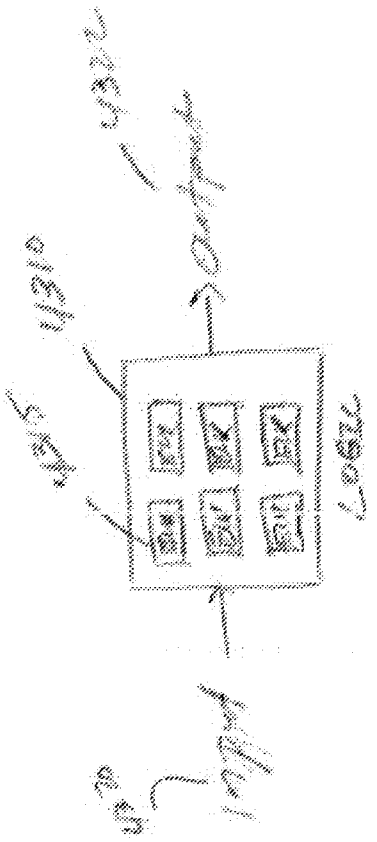
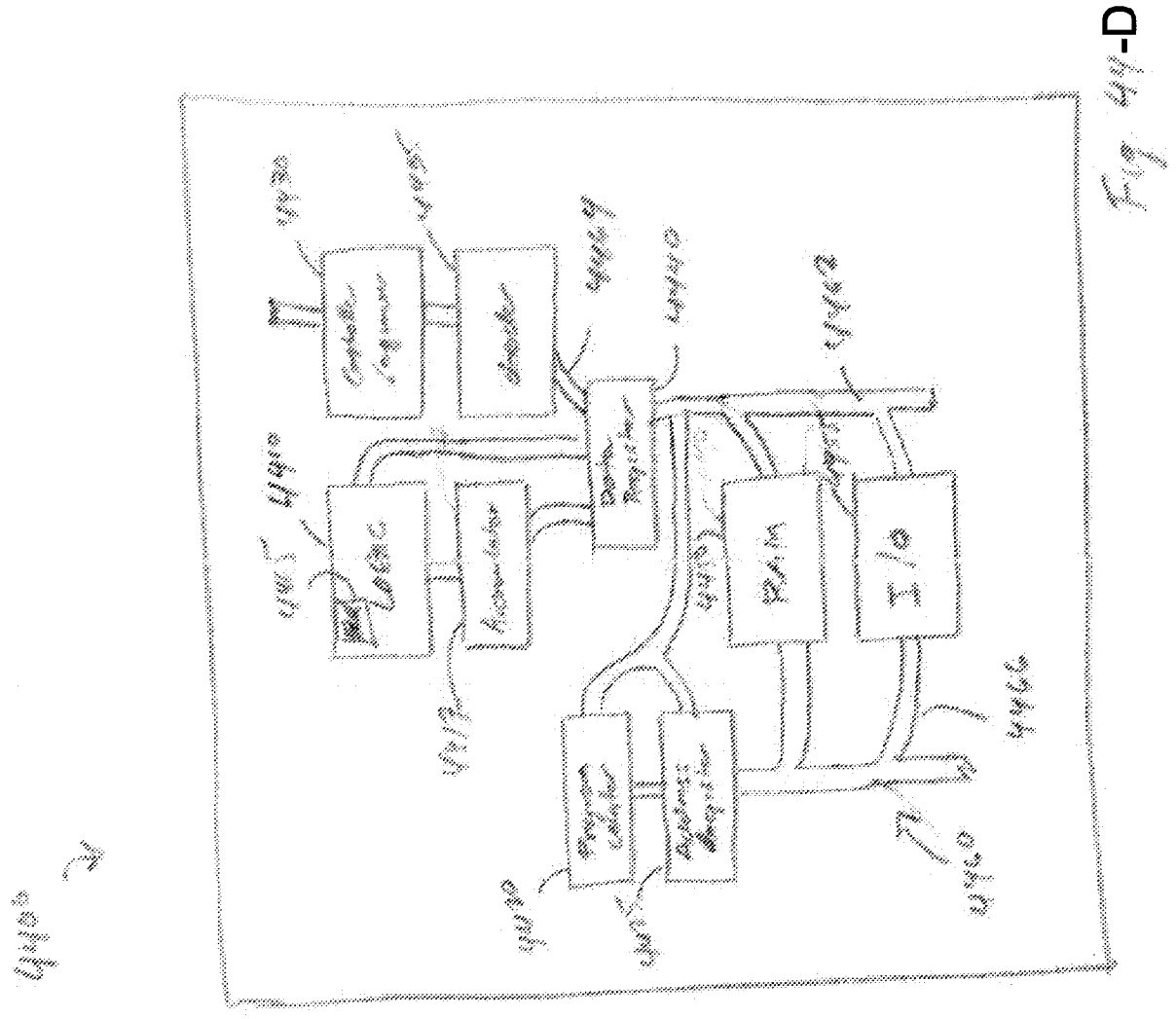

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Source
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Figure 41-D


Fig. 42-D
Generic display system
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Memory
4216
Input device
4220


Fig 49-D
Fig 49-A
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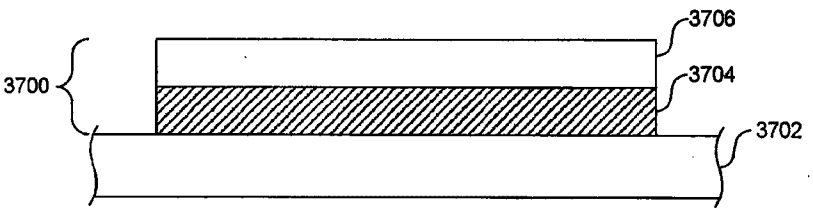


FIG. 37-E

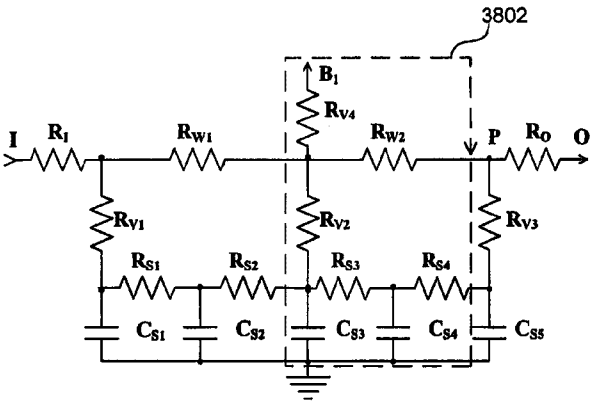

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FIG. 38-E

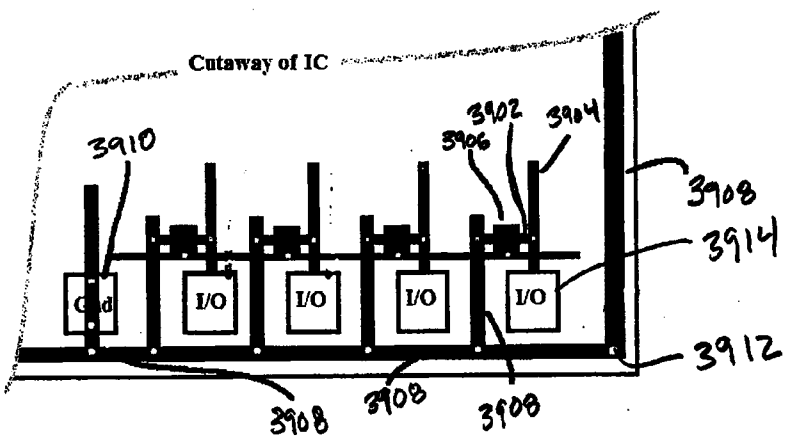

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FIG. 39-E

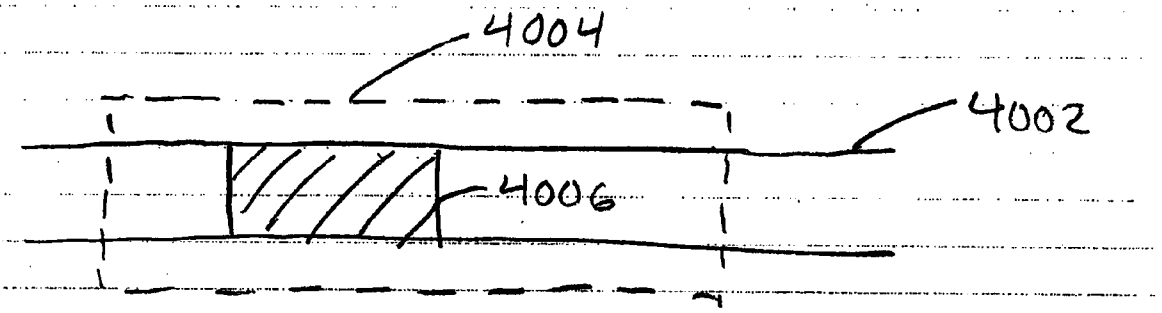


FIG 40-E

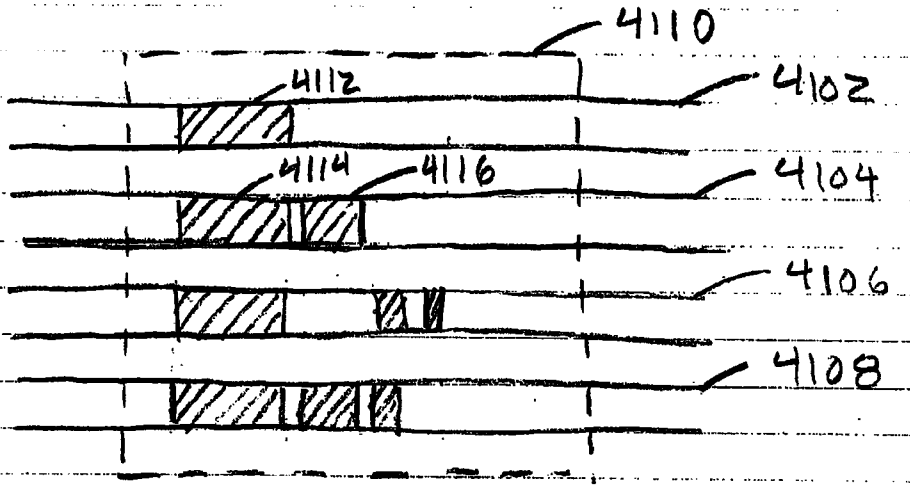


FIG 41-E

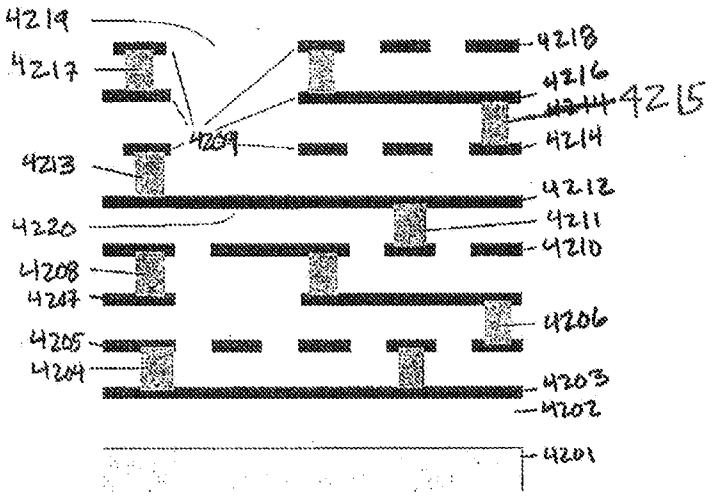

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FIG. 42-E

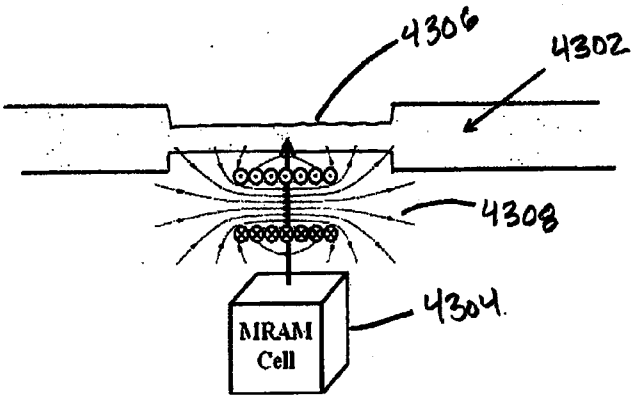


FIG. 43-E

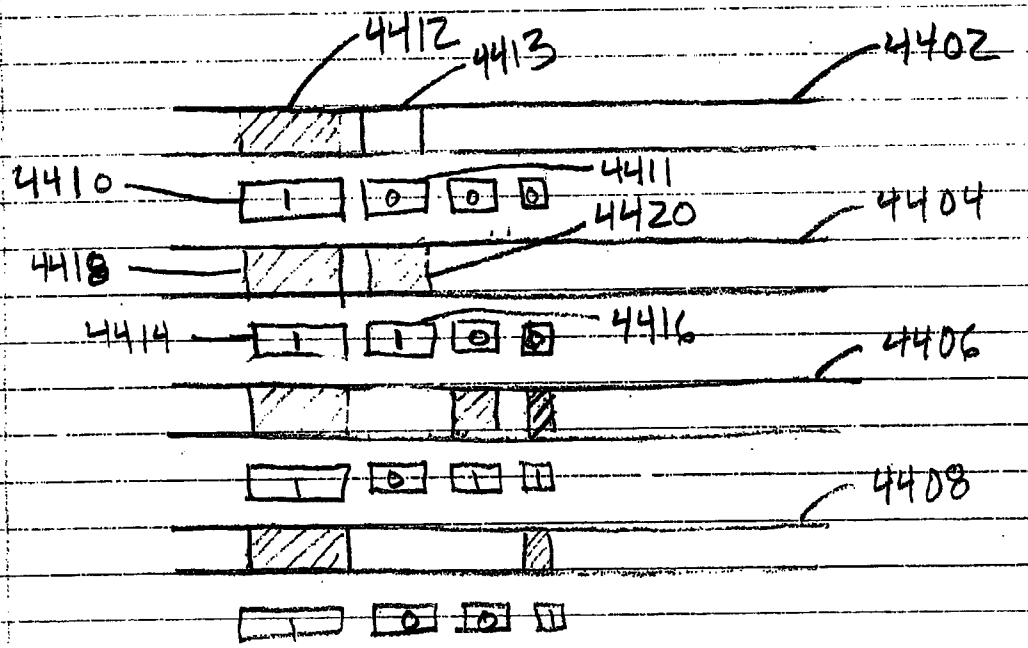


FIG 44-E

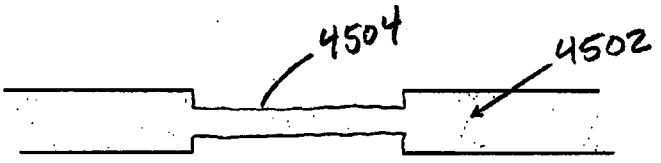


FIG. 45-E

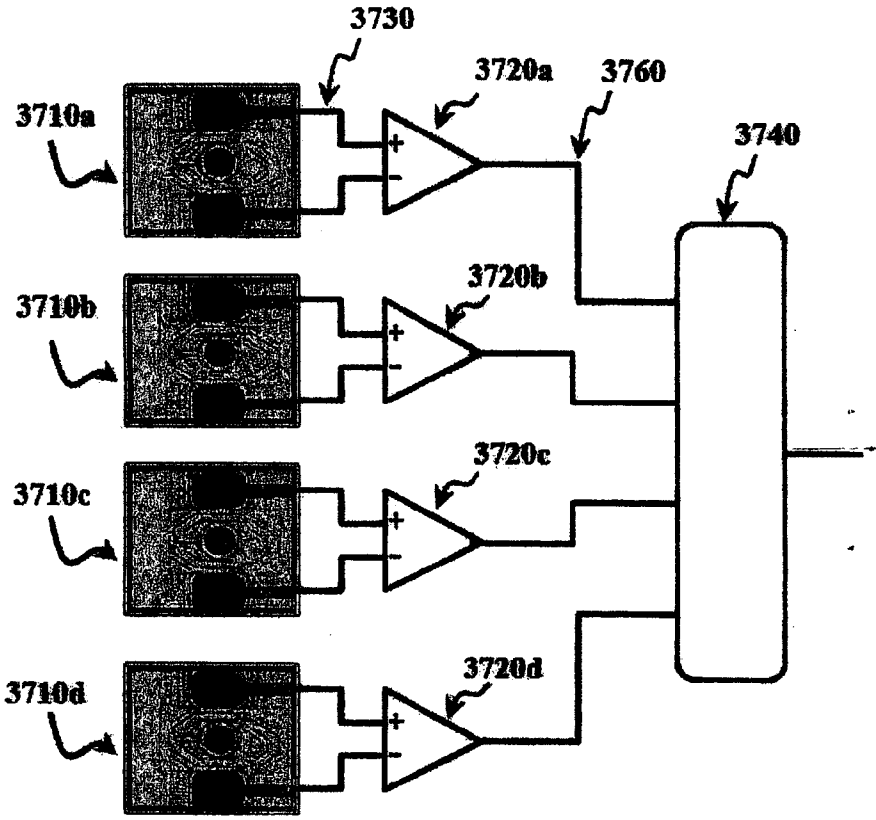

3730
3720a
3760
3740
3710a
3720b
3710b
3720c
3710c
3720d
3710d

FIG. 37-F

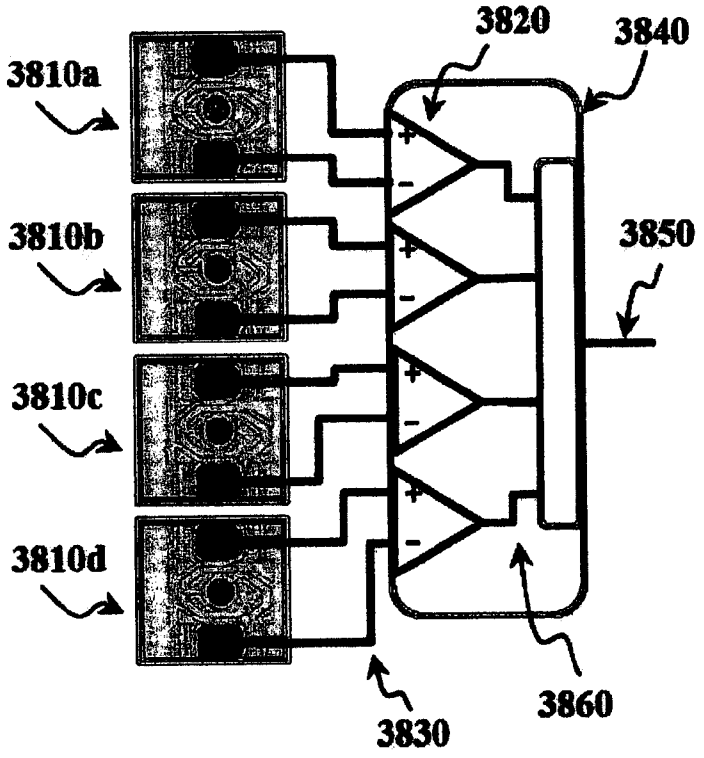


FIG. 38-F

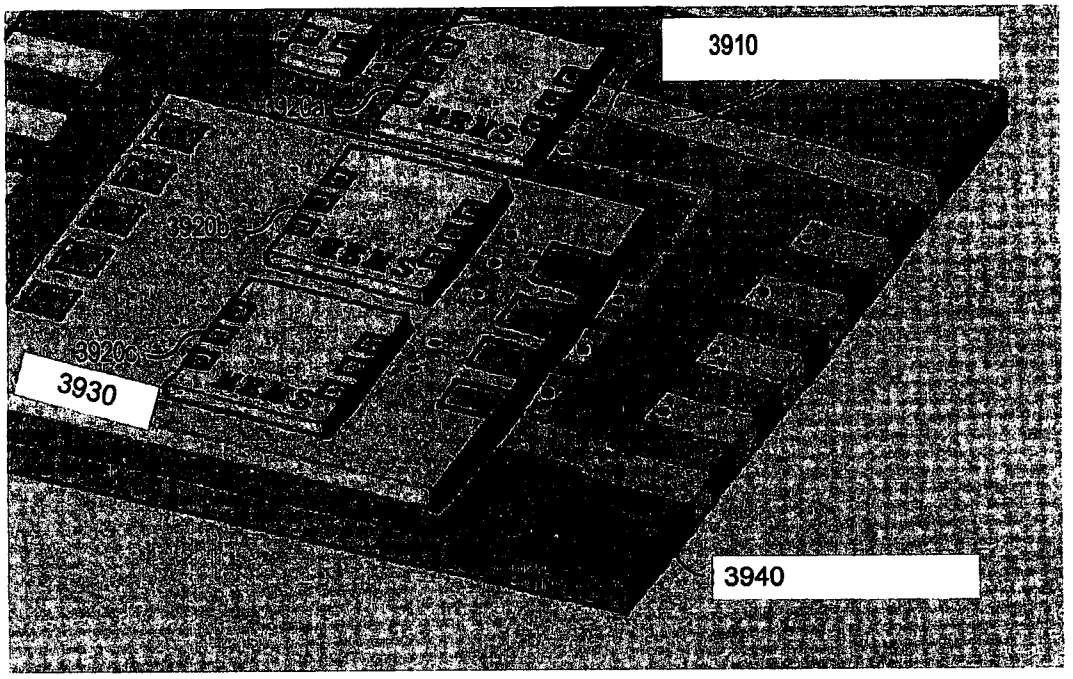


FIG. 39-F

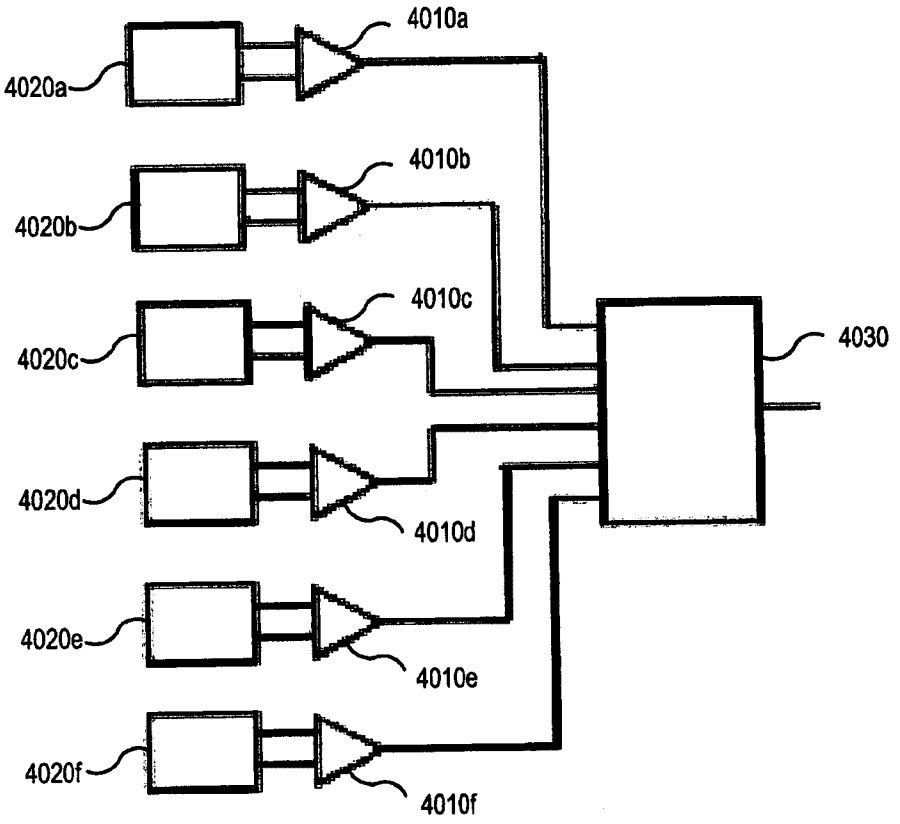

4010a
4020a
4010b
4020b
4010c
4020c
4030
4020d
4010d
4020e
4010e
4020f
4010f

FIG. 40-F

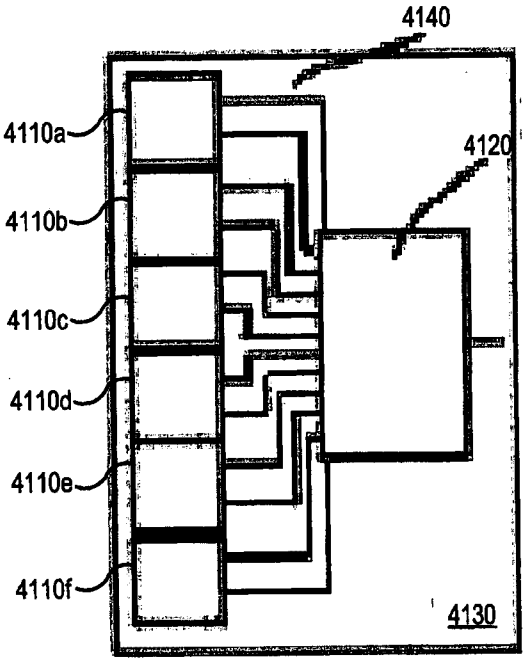


FIG. 41-F

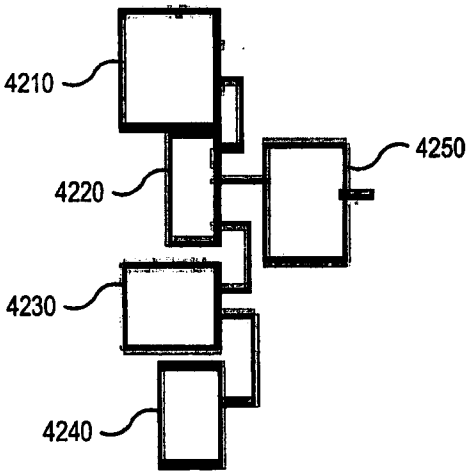


FIG. 42-F

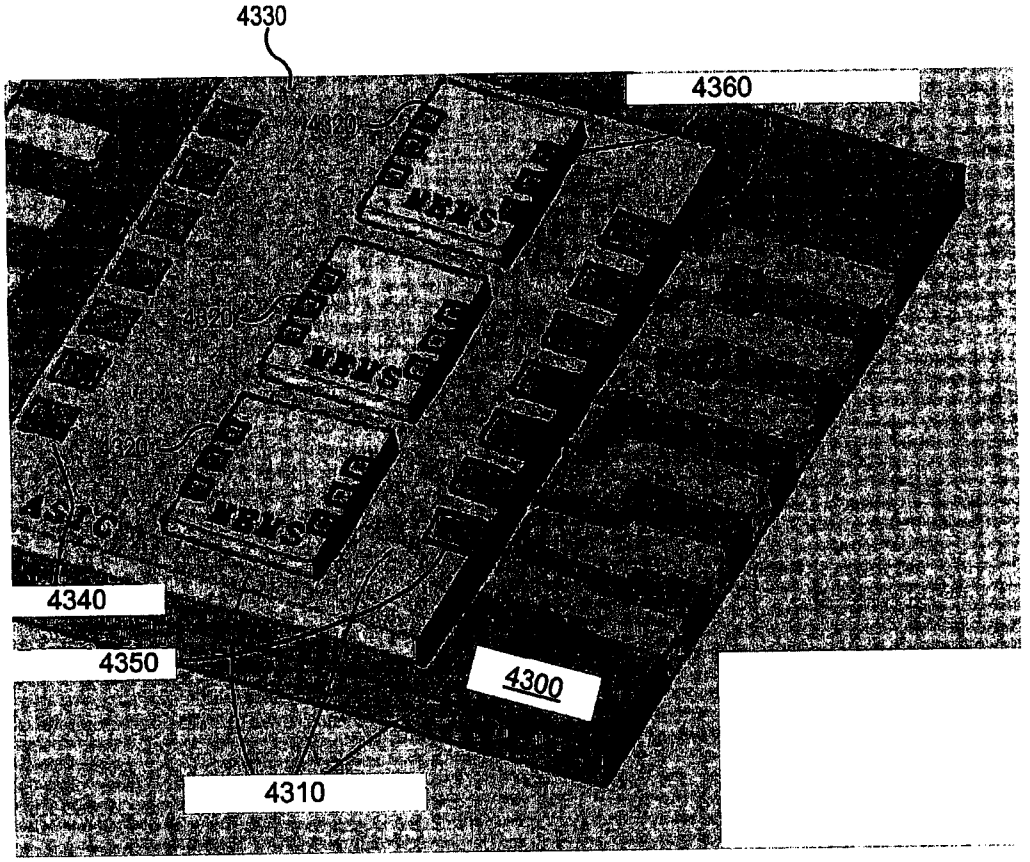


FIG. 43-F

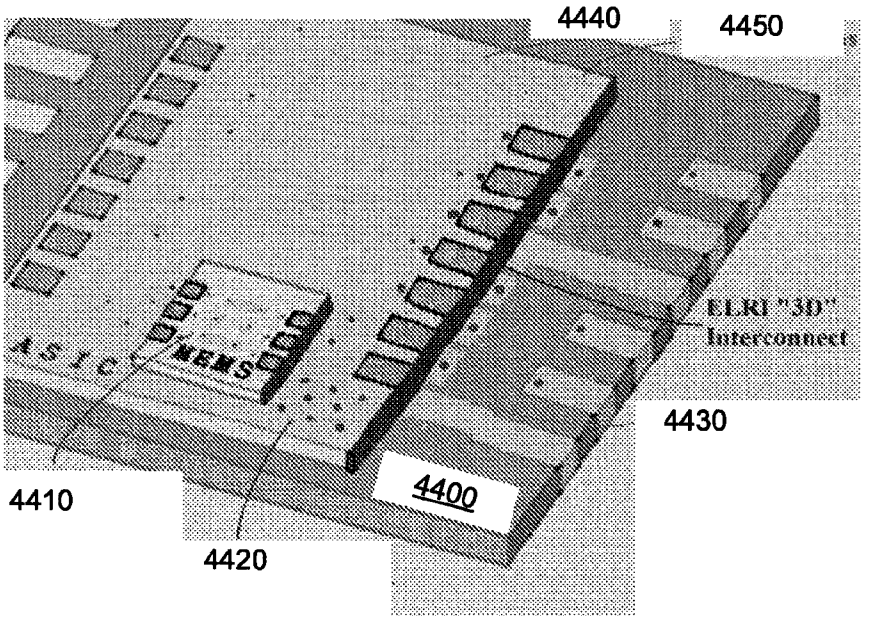

4440
4450
ASIC
MEMS
ELRI "3D"
Interconnect
4430
4410
4400
4420

FIG. 44-F

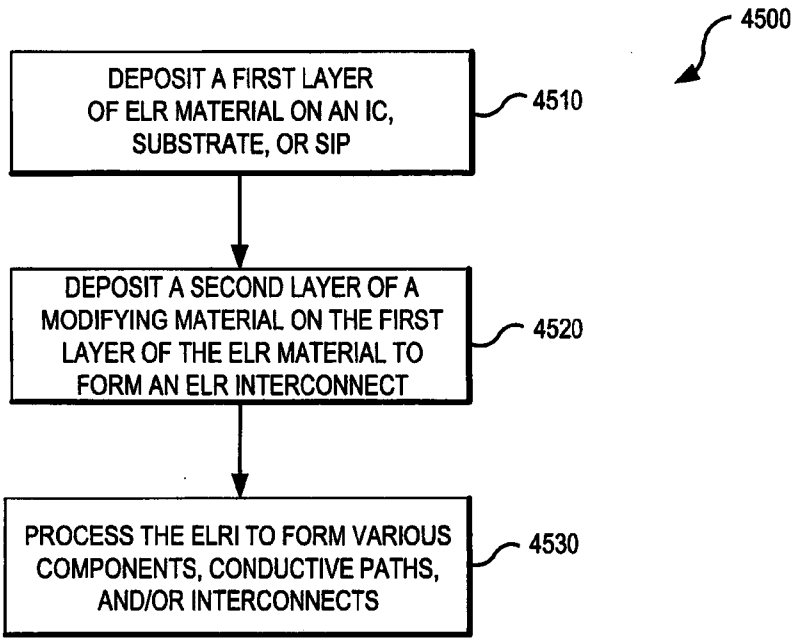

4500
DEPOSIT A FIRST LAYER OF ELR MATERIAL ON AN IC, SUBSTRATE, OR SIP
4510
DEPOSIT A SECOND LAYER OF A MODIFYING MATERIAL ON THE FIRST LAYER OF THE ELR MATERIAL TO FORM AN ELR INTERCONNECT
4520
PROCESS THE ELRI TO FORM VARIOUS COMPONENTS, CONDUCTIVE PATHS, AND/OR INTERCONNECTS
4530

FIG. 45-F

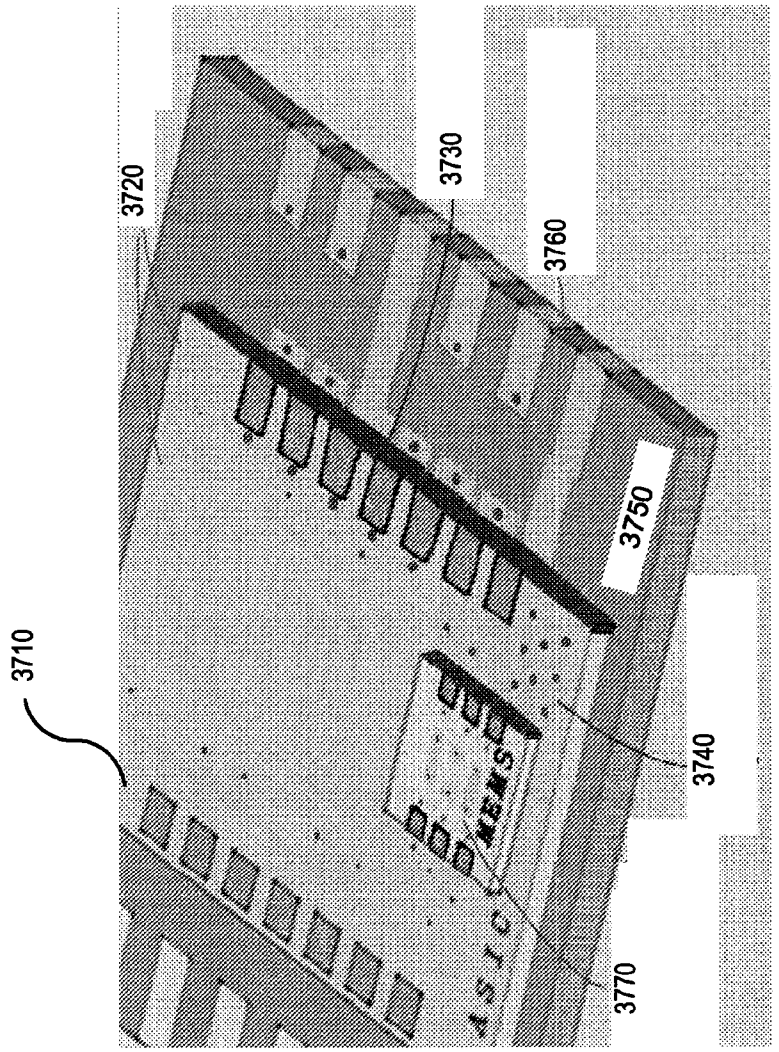


FIG 37-G

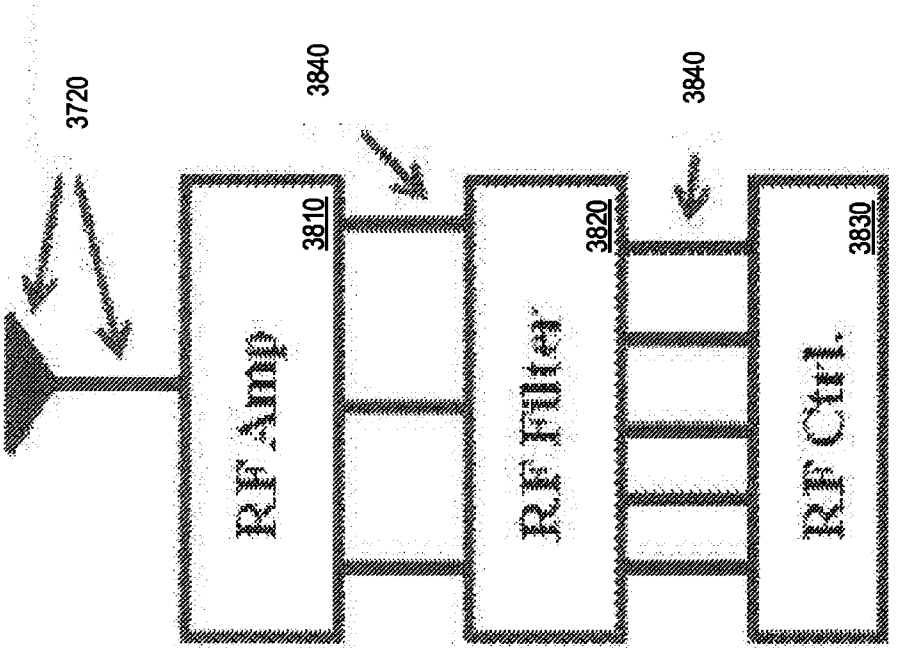


FIG 38-G

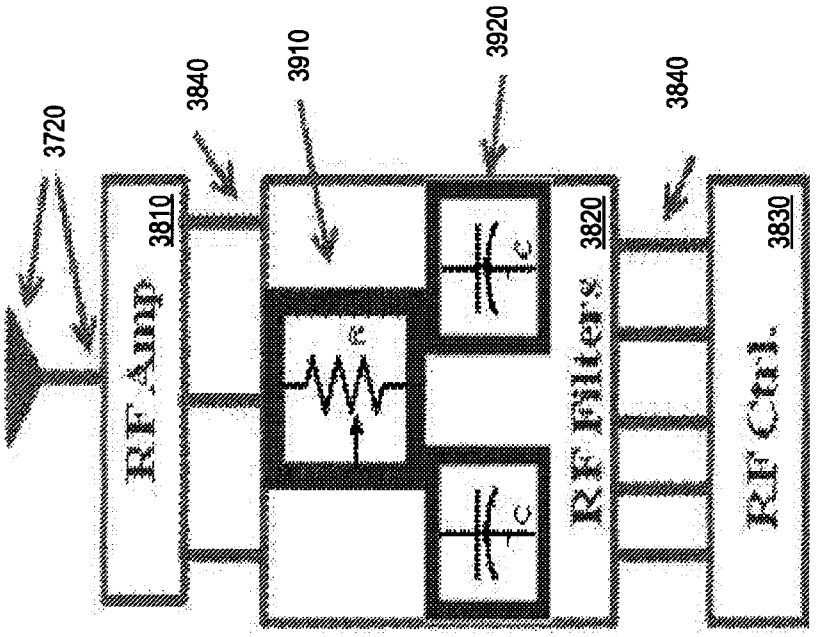

3720
3840
3910
3920
3840
RF Amp
3810
RF Filters
3820
RF Ctrl.
3830

FIG 39-G

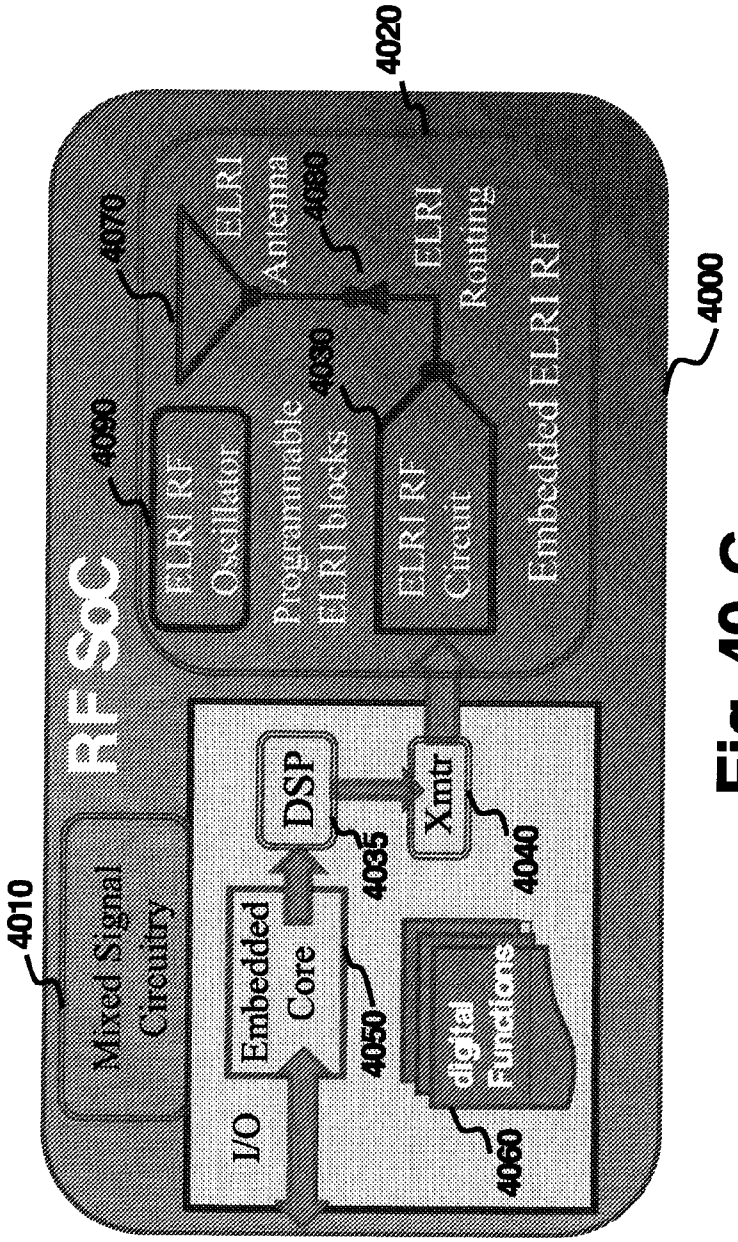

4020
4070
ELRI
Antenna
4080
ELRI
Roming
4030
Programmable
ELRI blocks
4090
ELRI RF
Oscillator
ELRI RF
Circuit
Embedded ELRI RF
4000
4010
Mixed Signal
Circuitry
RF SoC
I/O
Embedded
Core
4050
DSP
4035
Xmtr
4040
digital
Functions
4060

Fig. 40-G

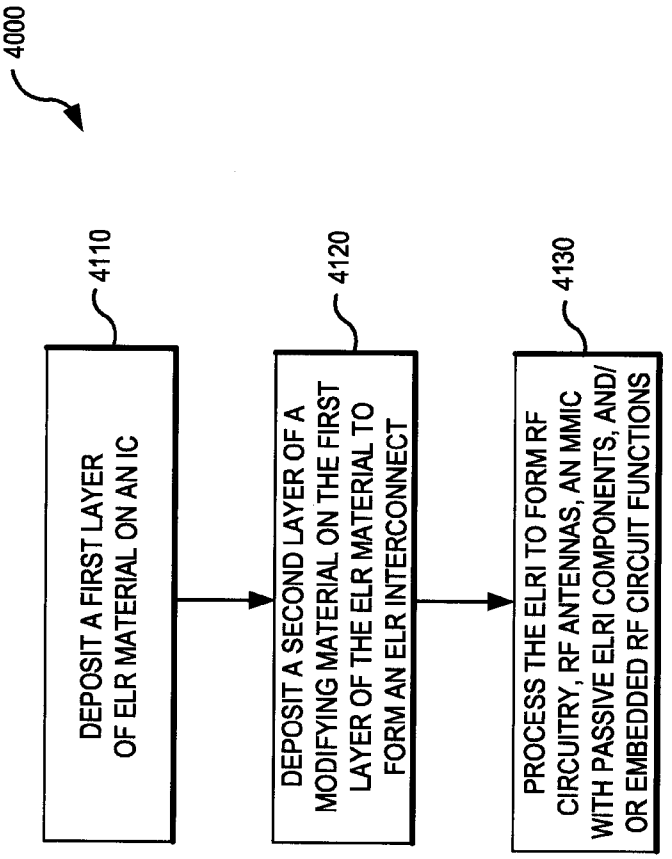

4000
4110
DEPOSIT A FIRST LAYER OF ELR MATERIAL ON AN IC
4120
DEPOSIT A SECOND LAYER OF A MODIFYING MATERIAL ON THE FIRST LAYER OF THE ELR MATERIAL TO FORM AN ELR INTERCONNECT
4130
PROCESS THE ELRI TO FORM RF CIRCUITRY, RF ANTENNAS, AN MMIC WITH PASSIVE ELRI COMPONENTS, AND/OR EMBEDDED RF CIRCUIT FUNCTIONS

FIG 41-G

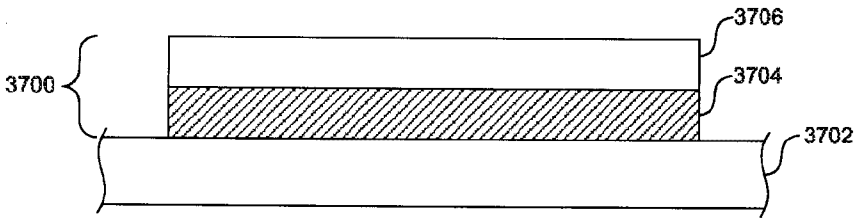


FIG. 37-H

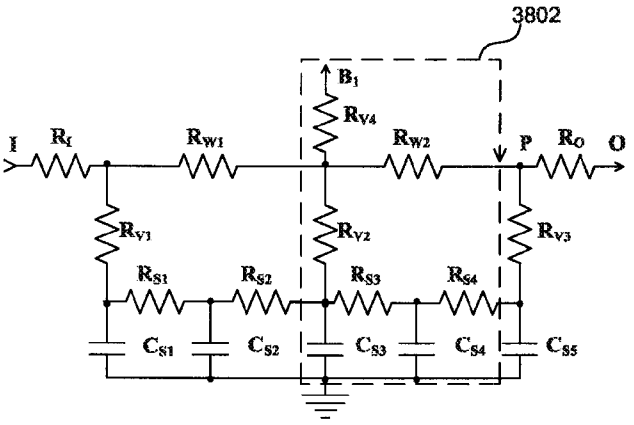

3802
B1
RV4
I
RI
RW1
RW2
P
RO
O
RV1
RV2
RV3
RS1
RS2
RS3
RS4
CS1
CS2
CS3
CS4
CS5

FIG. 38-H

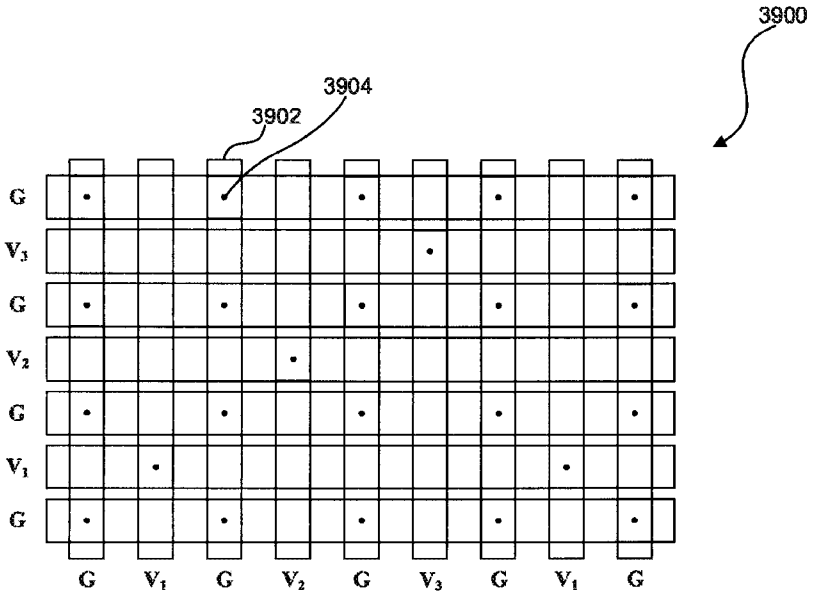


FIG. 39-H

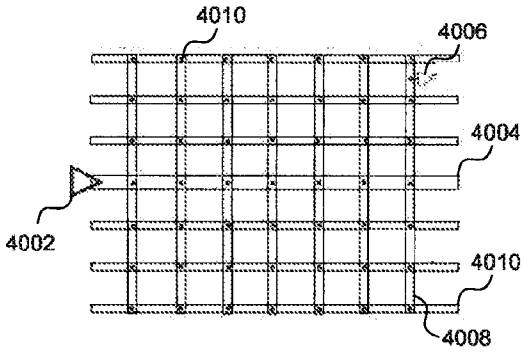


FIG. 40A-H

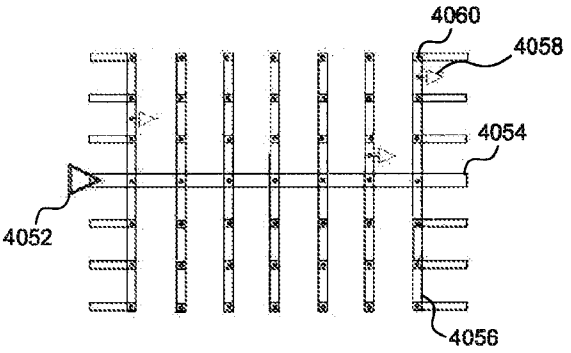


FIG. 40B-H

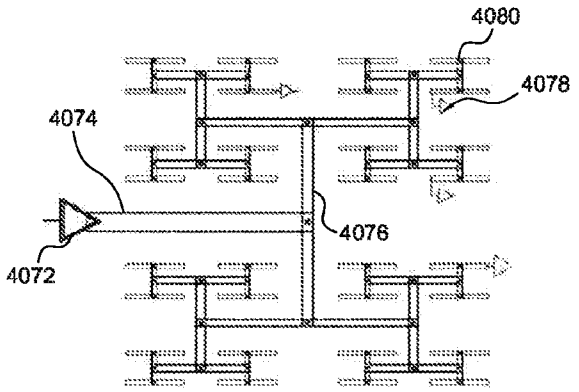


FIG. 40C-H

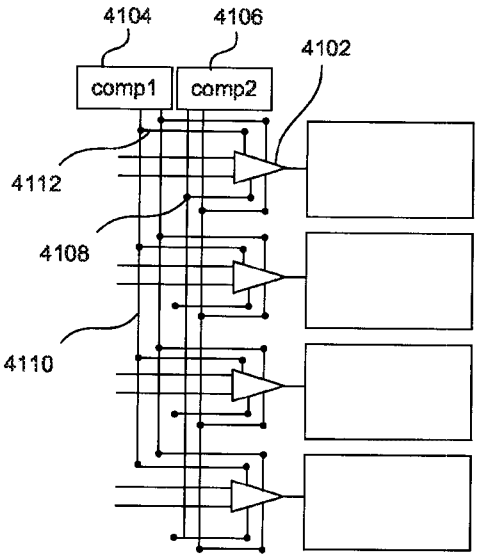


FIG. 41-H

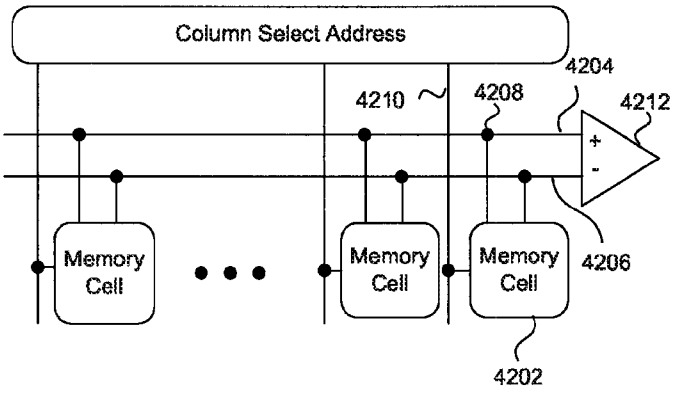

Column Select Address
4204
4210
4208
4212
+
-
Memory Cell
Memory Cell
Memory Cell
4206
4202

FIG. 42-H

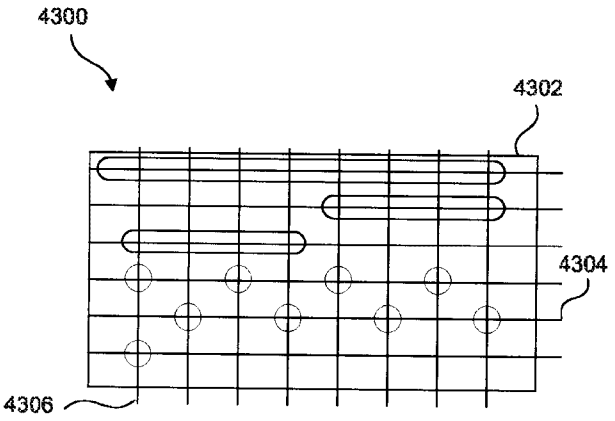


FIG. 43-H

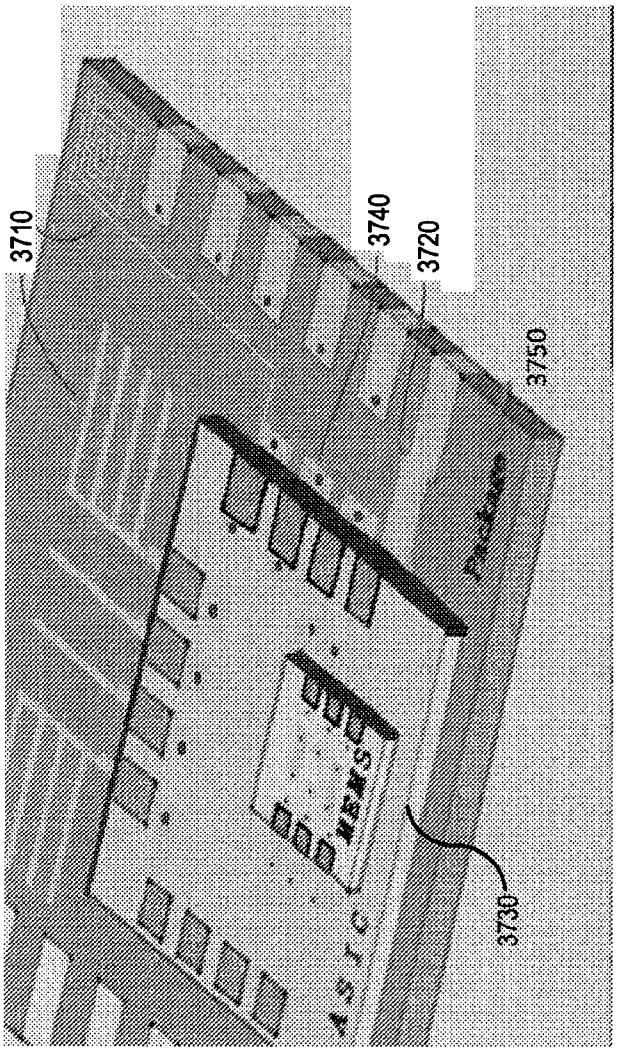


FIG 37-I

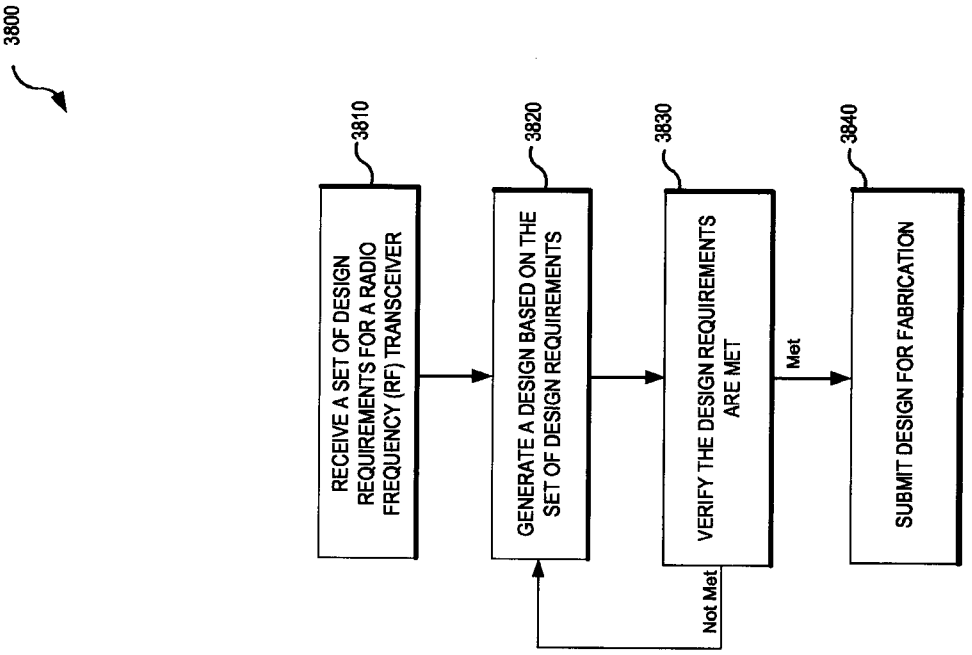

3800
3810
RECEIVE A SET OF DESIGN REQUIREMENTS FOR A RADIO FREQUENCY (RF) TRANSCEIVER
3820
GENERATE A DESIGN BASED ON THE SET OF DESIGN REQUIREMENTS
3830
VERIFY THE DESIGN REQUIREMENTS ARE MET
Met
Not Met
3840
SUBMIT DESIGN FOR FABRICATION

FIG. 38-I

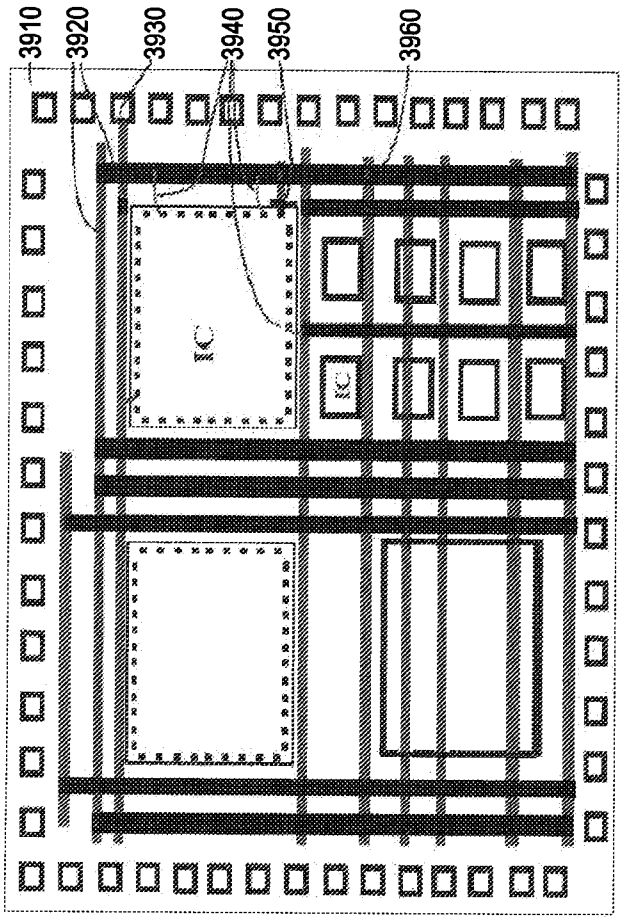


FIG. 39-I

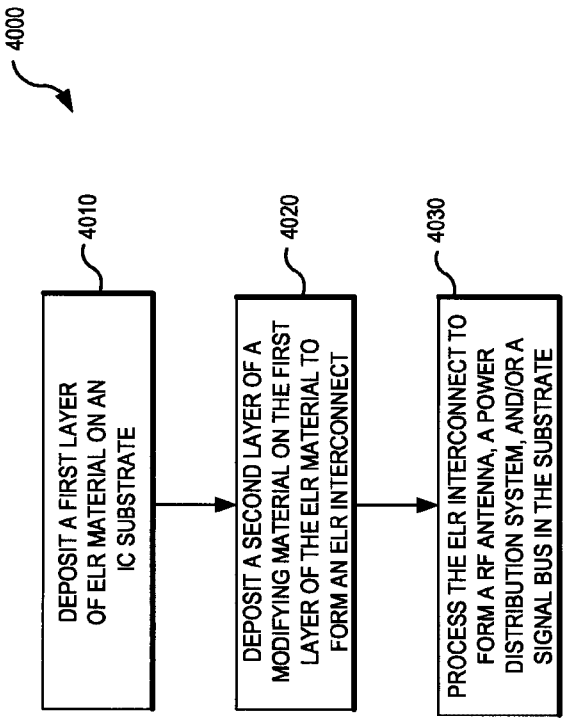

4000
4010
DEPOSIT A FIRST LAYER OF ELR MATERIAL ON AN IC SUBSTRATE
4020
DEPOSIT A SECOND LAYER OF A MODIFYING MATERIAL ON THE FIRST LAYER OF THE ELR MATERIAL TO FORM AN ELR INTERCONNECT
4030
PROCESS THE ELR INTERCONNECT TO FORM A RF ANTENNA, A POWER DISTRIBUTION SYSTEM, AND/OR A SIGNAL BUS IN THE SUBSTRATE

FIG. 40-I

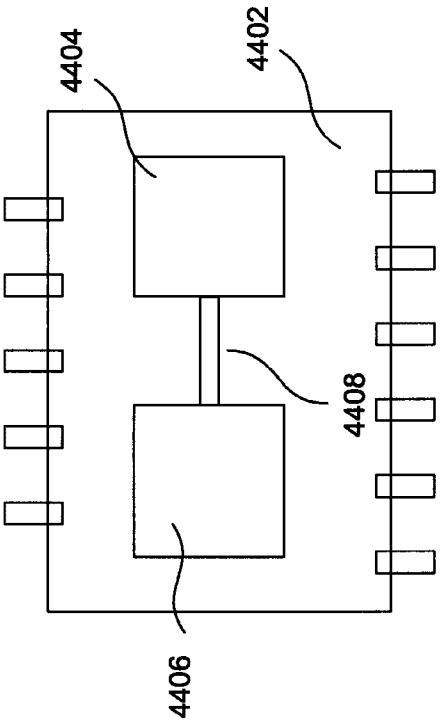


FIG. 41A-I

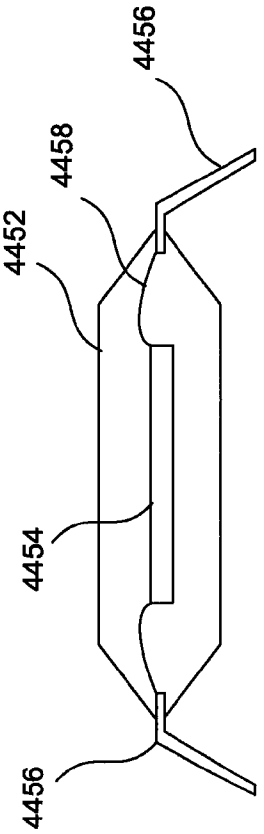


FIG. 41B-I

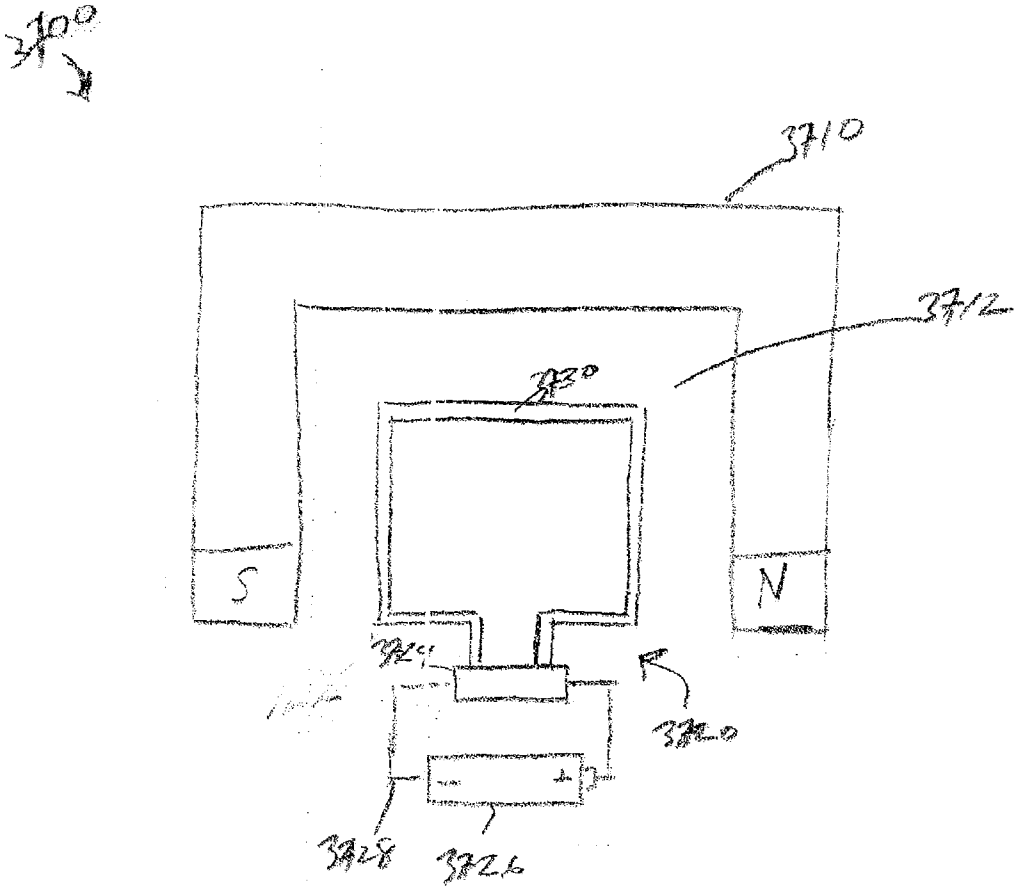


Fig 37A-J

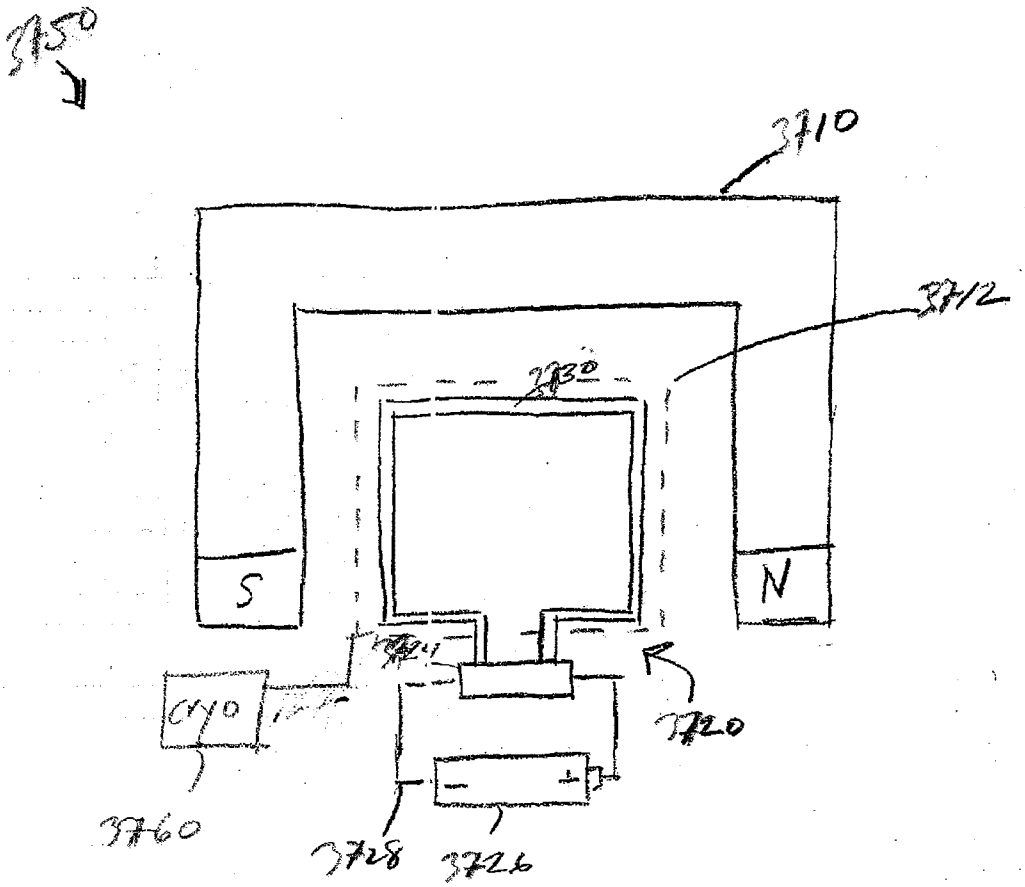


Fig 37B-J

3800

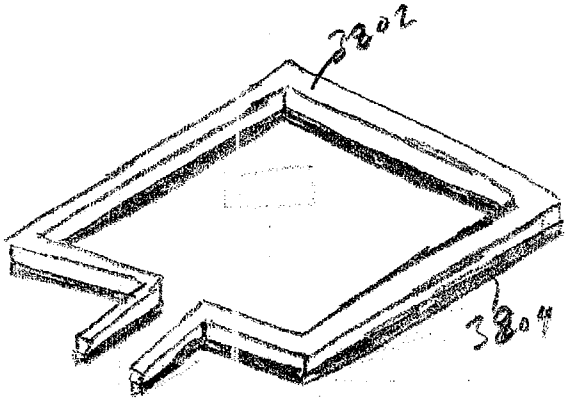


Fig 38A-J

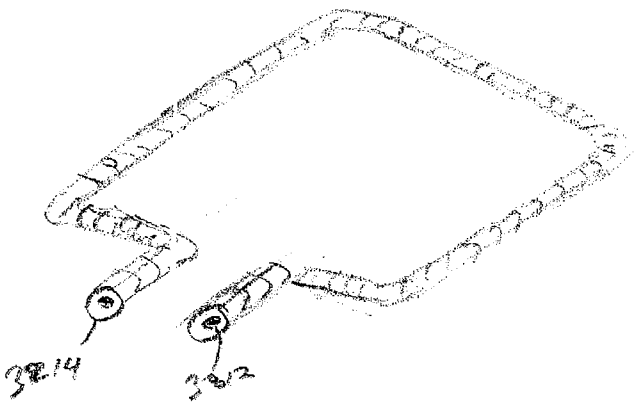


Fig 38B-J

3820

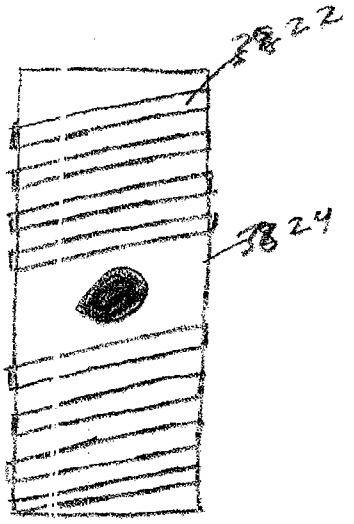


Fig 38C-J

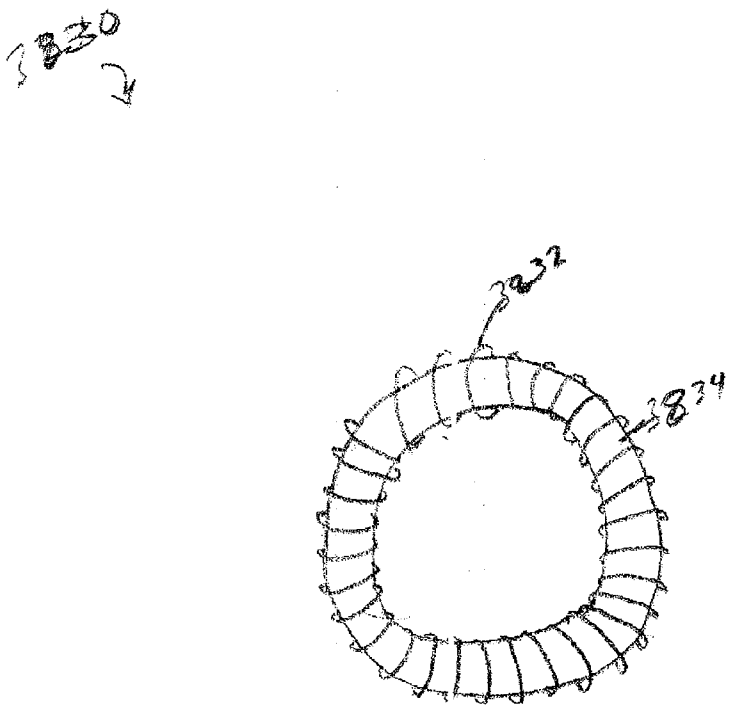


Fig 38 D-J

3840

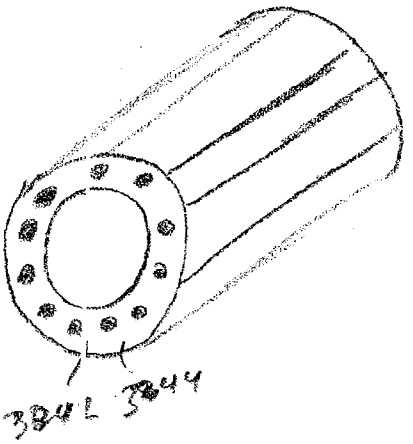


Fig 38 E-J

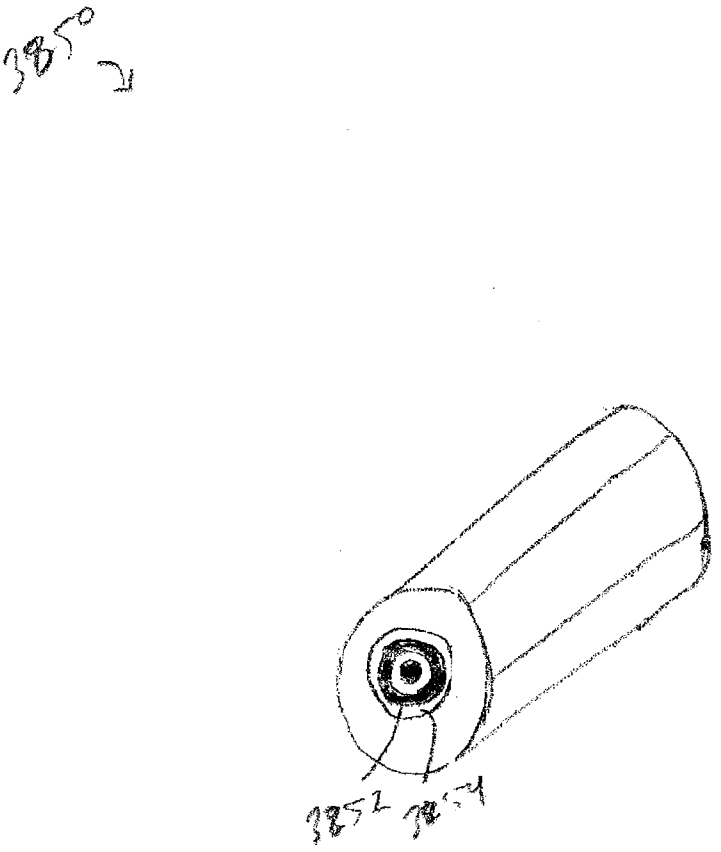


Fig 38 F-J

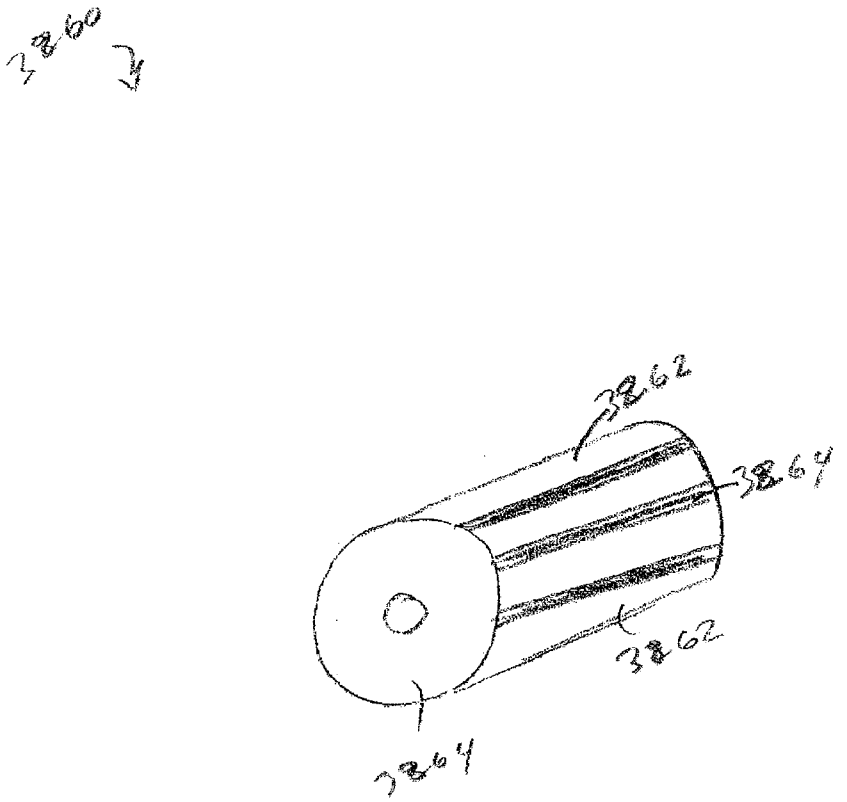


Fig 32G-J

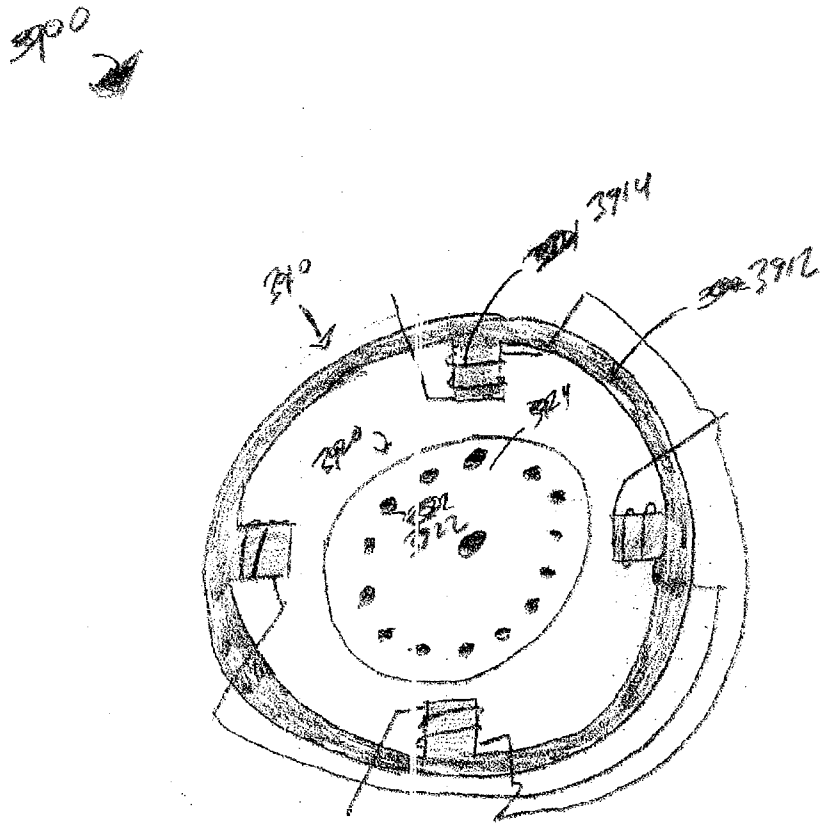


Fig 39-J

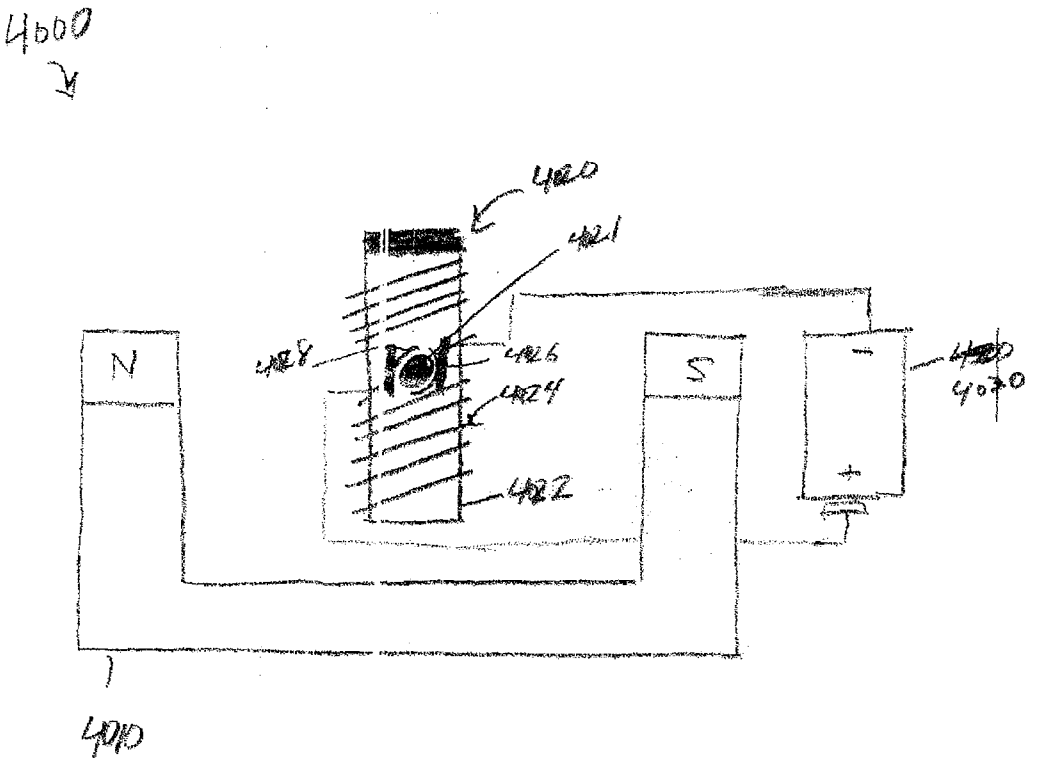


Fig 40-J

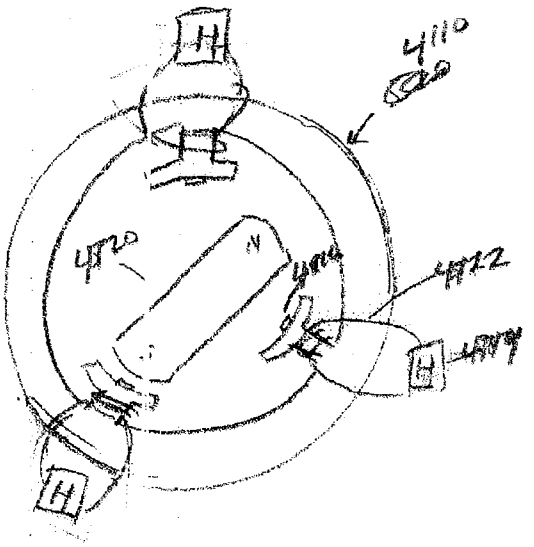


Fig 41-J

4200

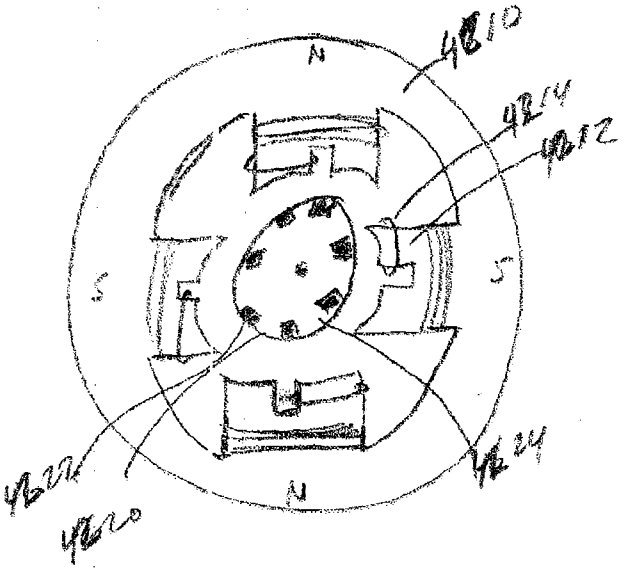


Fig 42-J

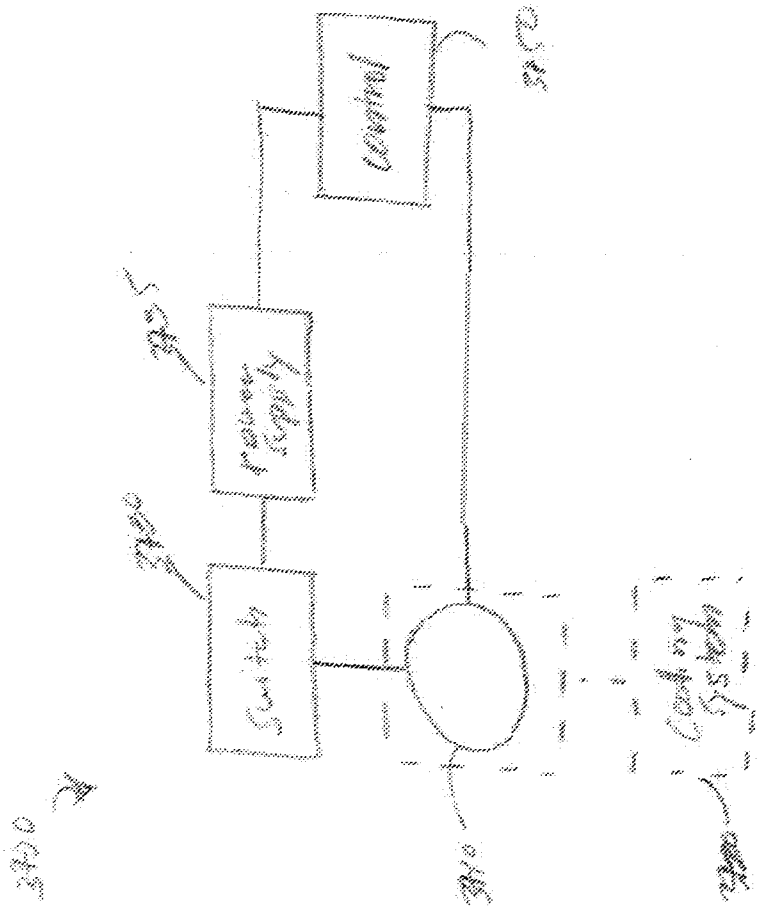


FIG 37A-K

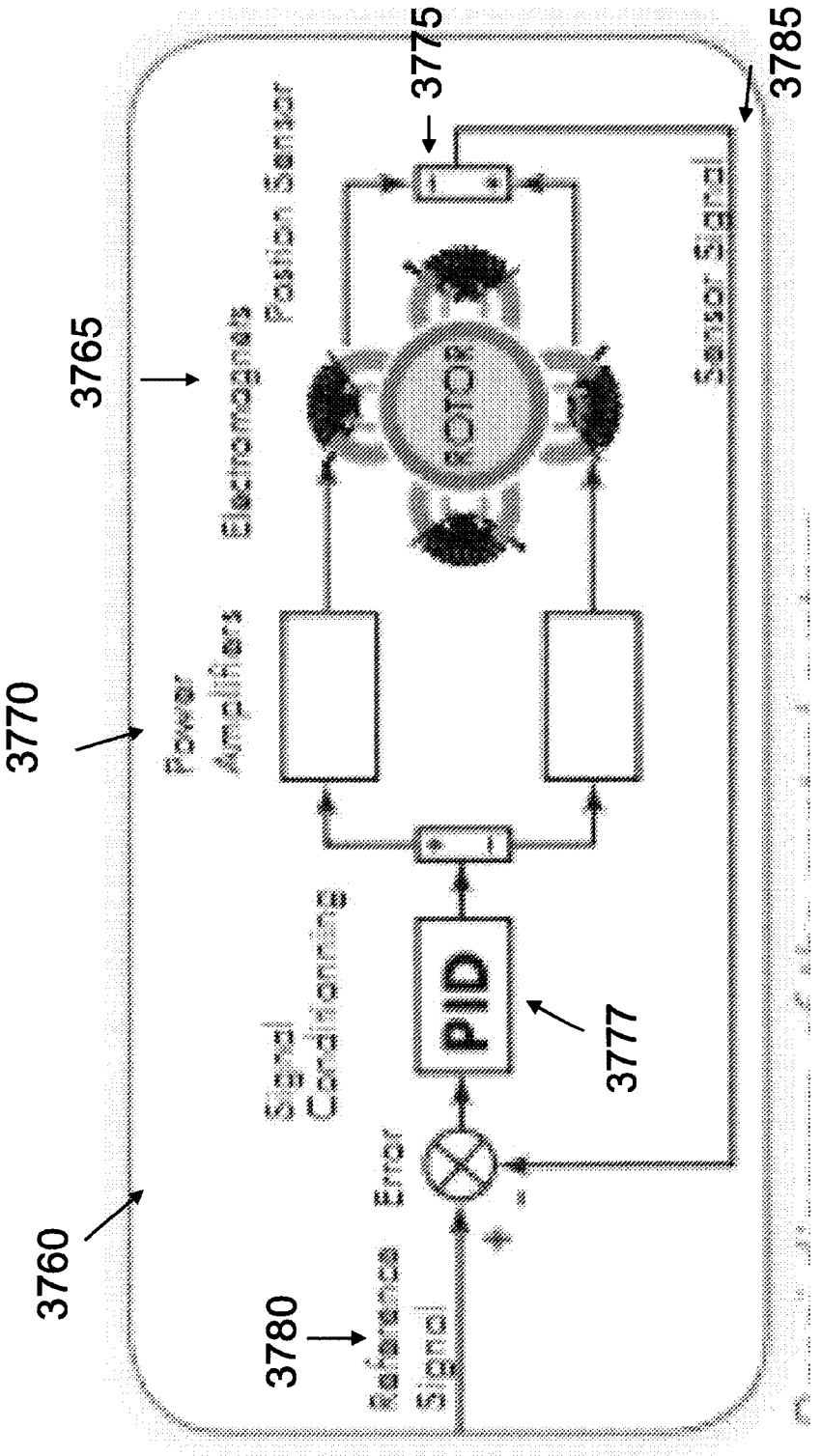

3760
3770
3765
3775
3785
3780
3777
Reference Signal
Error
Signal Conditioning
PID
Power Amplifiers
Electromagnets
Position Sensor
Rotor
Sensor Signal

FIG 37B-K

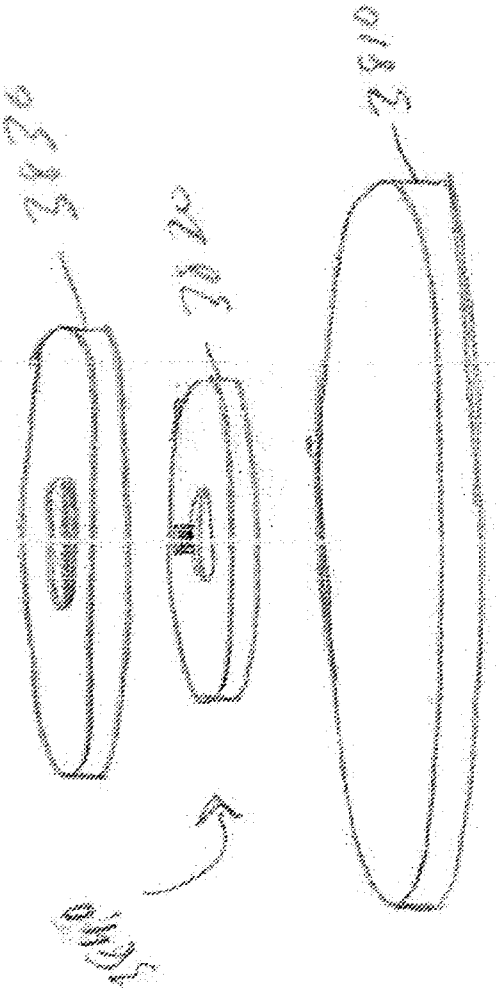


Fig. 26-K

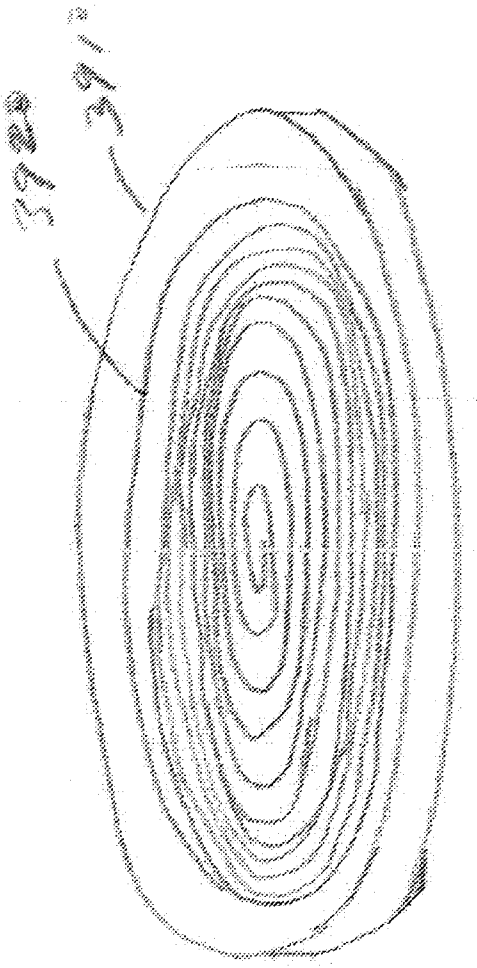


Fig 57A

Fig 57B-K

Fig 19B-K

Fig 19B-L

Fig. 4M-K

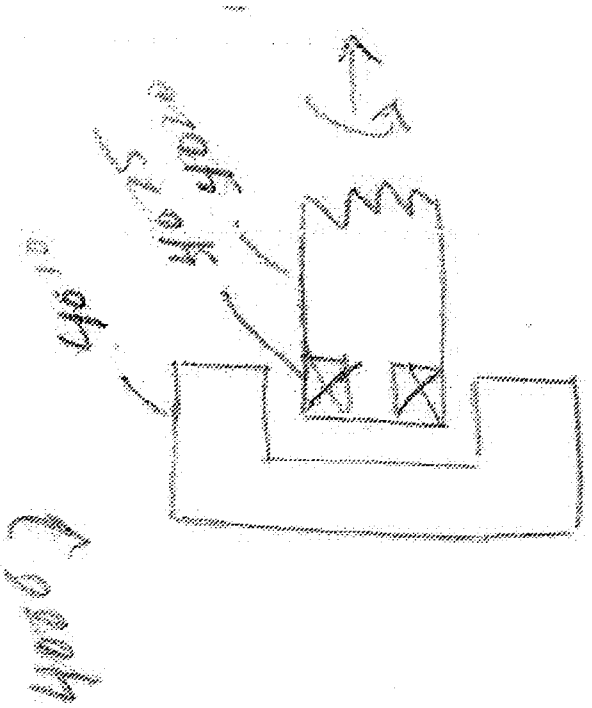


Fig. 4K
Fig. 4L

Fig. 10K

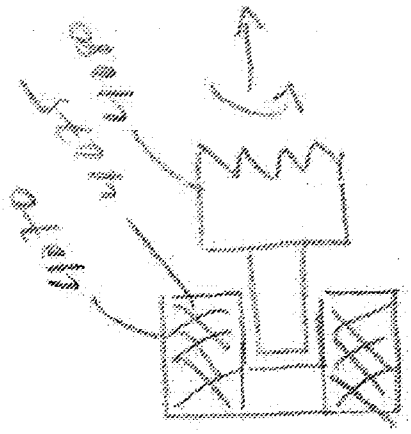


Fig. 10L

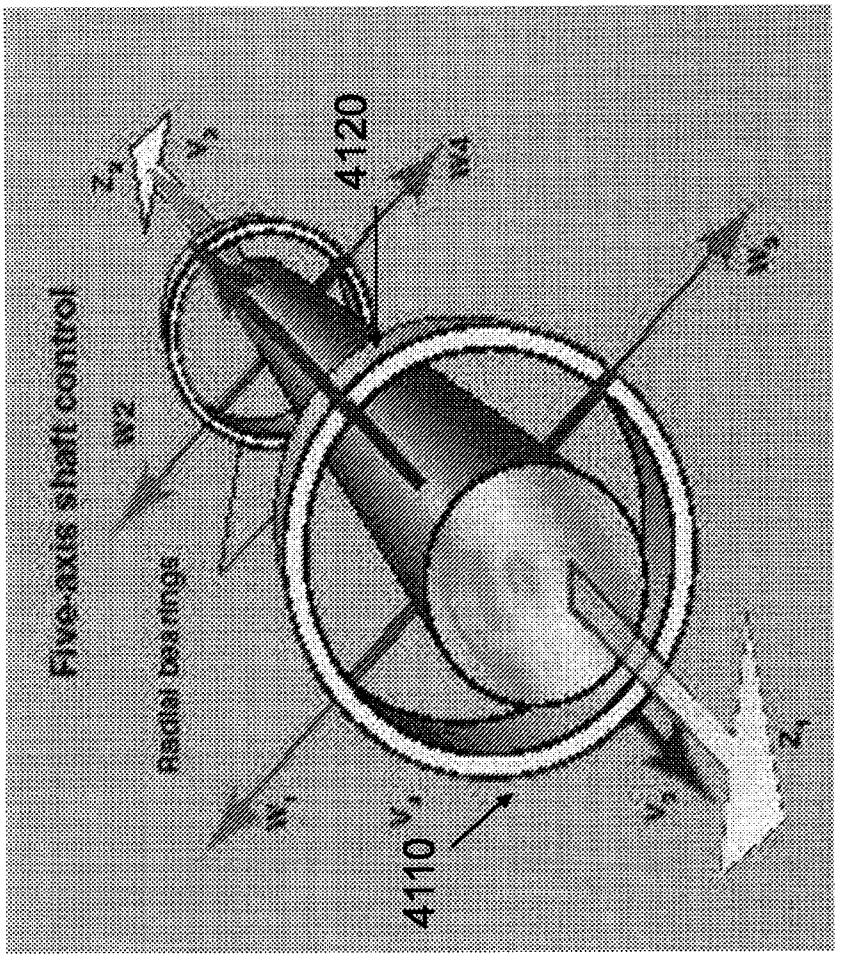


FIG 41-K

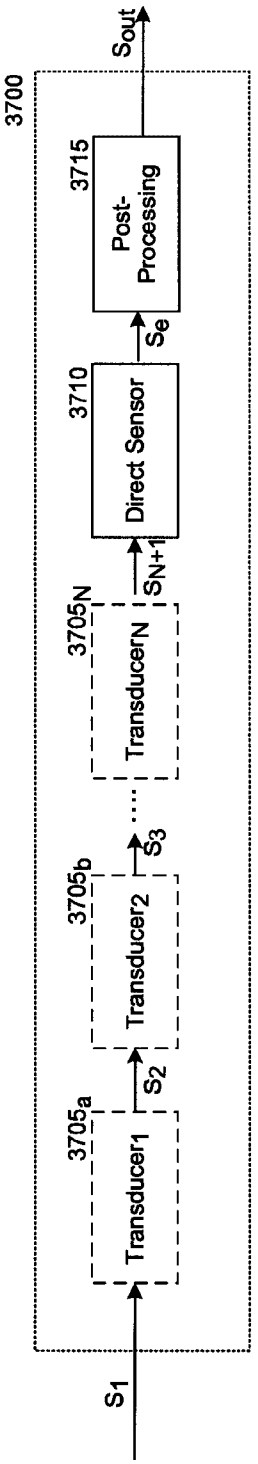

3700
Sout
3715
Post-Processing
Se
3710
Direct Sensor
SN+1
3705N
TransducerN
S3
3705b
Transducer2
S2
3705a
Transducer1
S1

FIG. 37-L

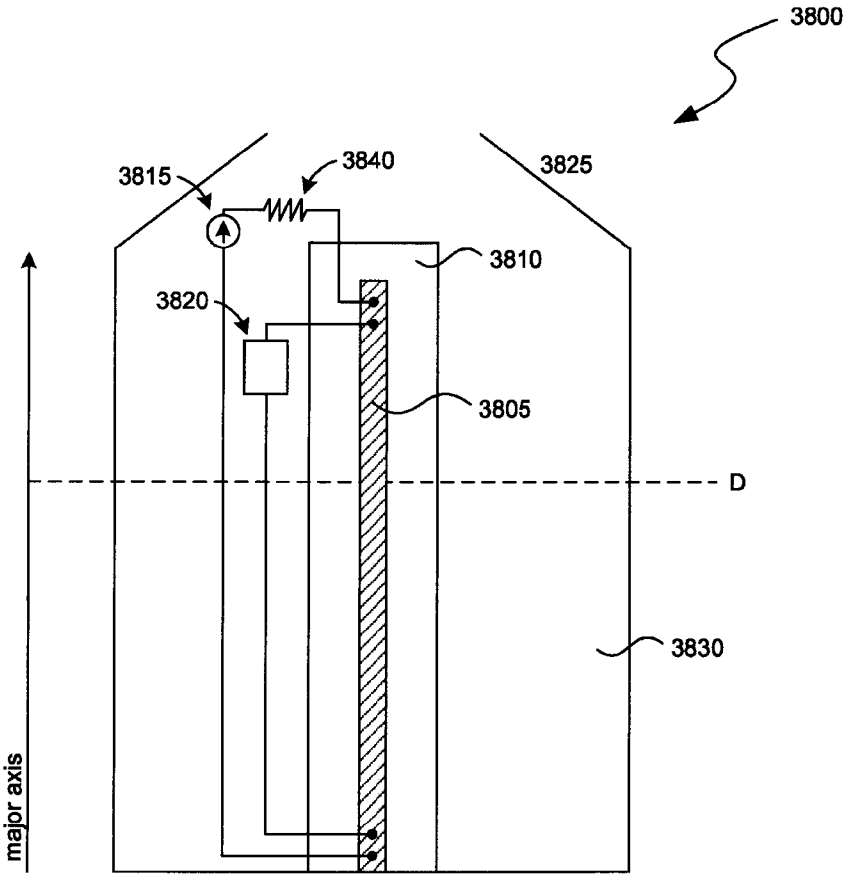


FIG. 38A-L

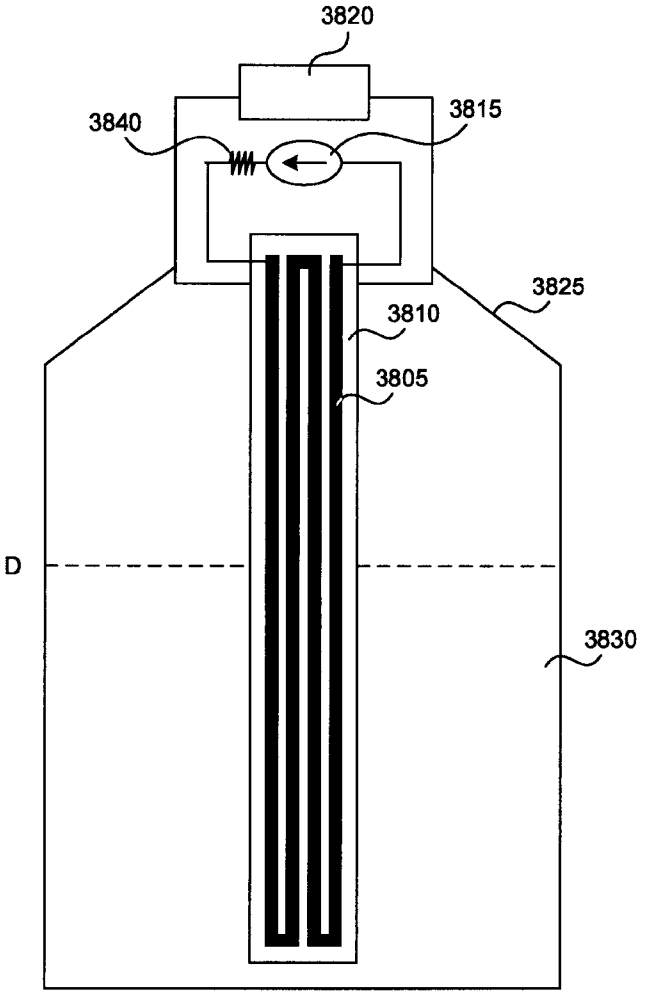


FIG. 38B-L

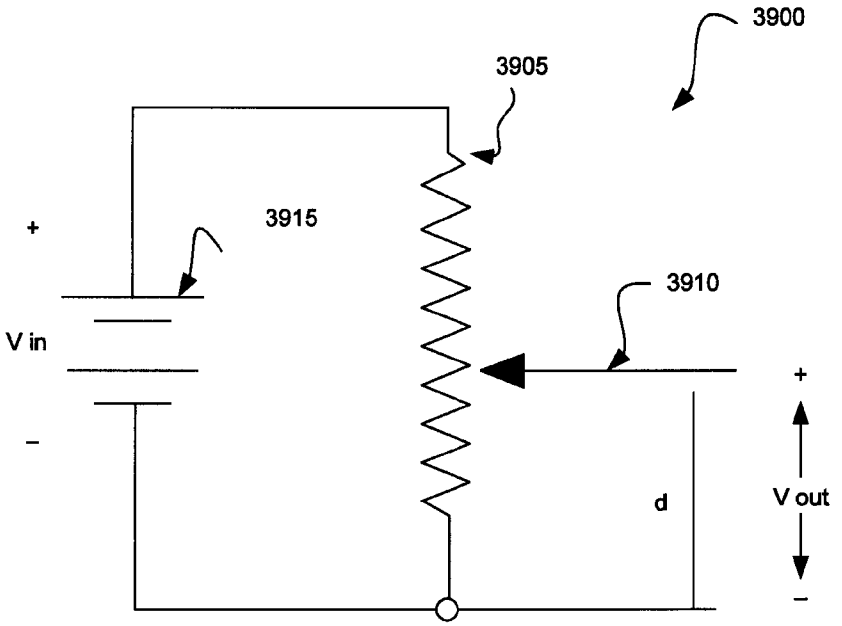


FIG. 39A-L

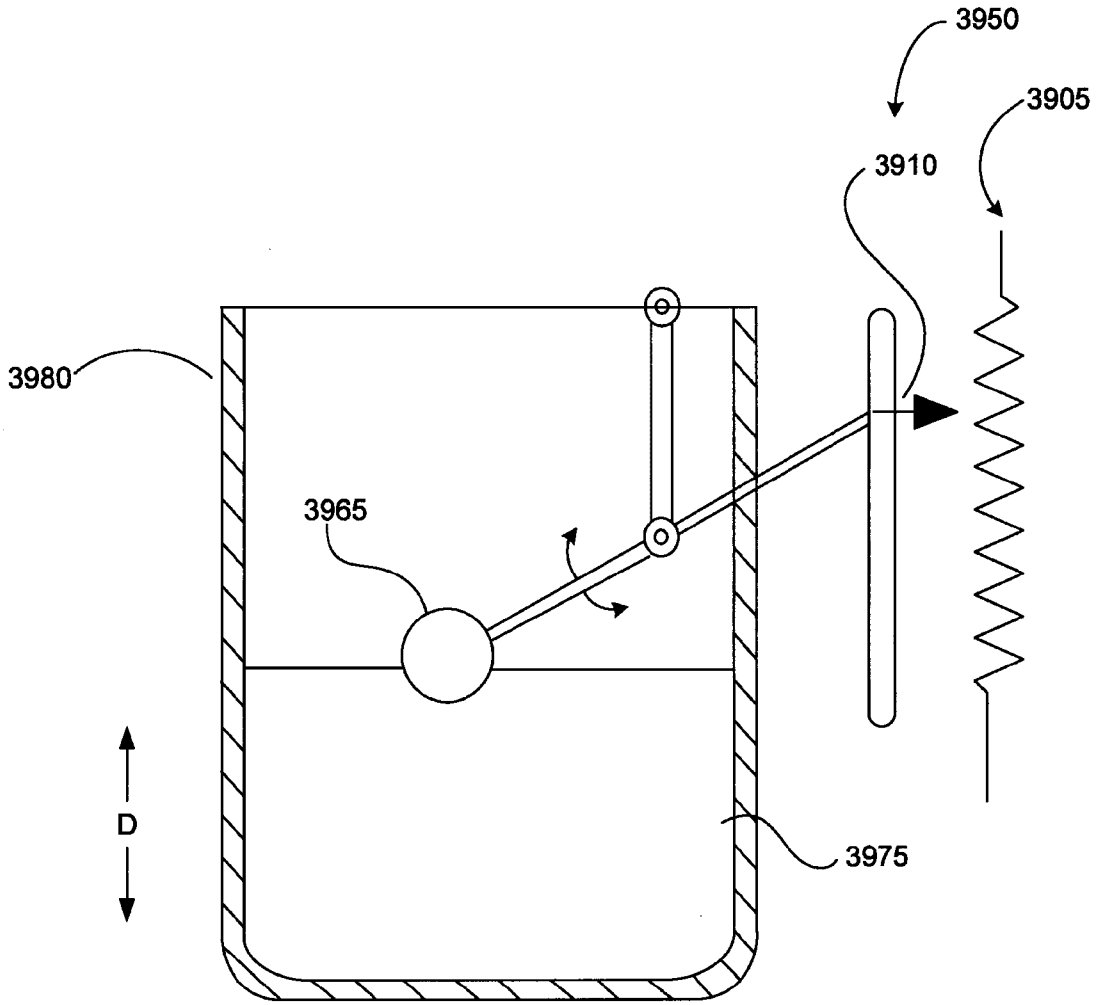


FIG. 39B-L

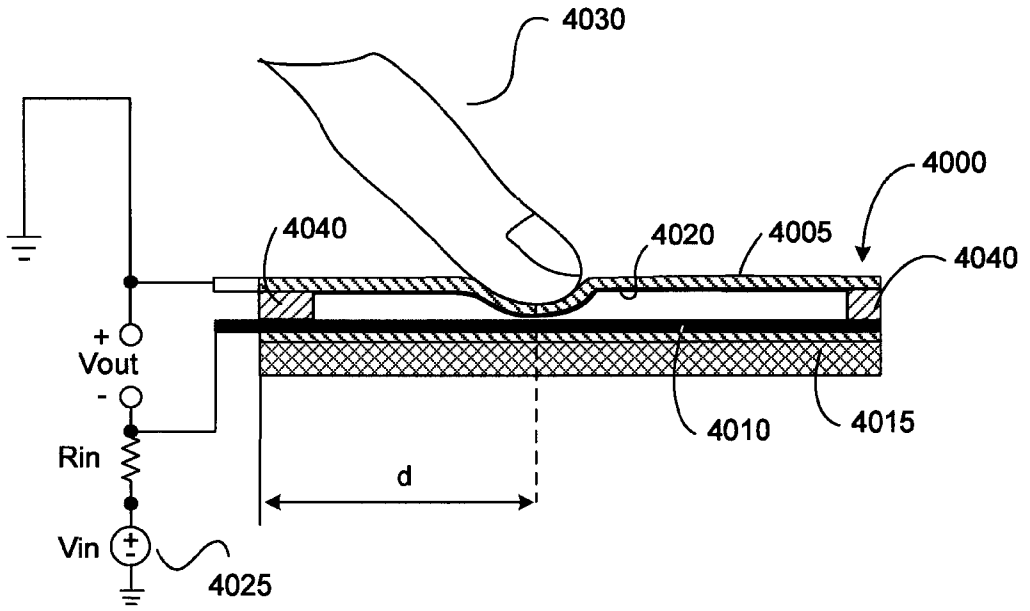


FIG. 40-L

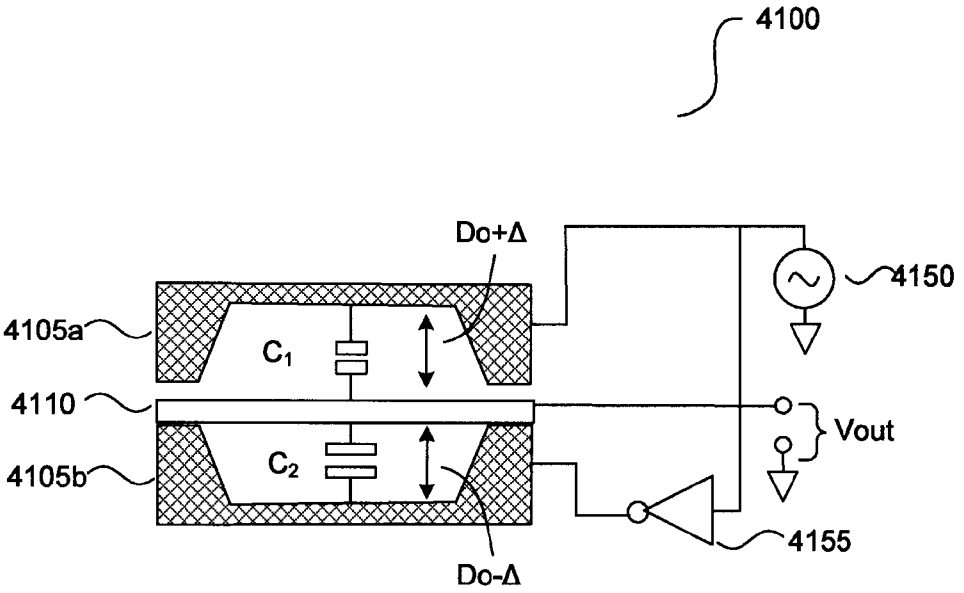


FIG. 41-L

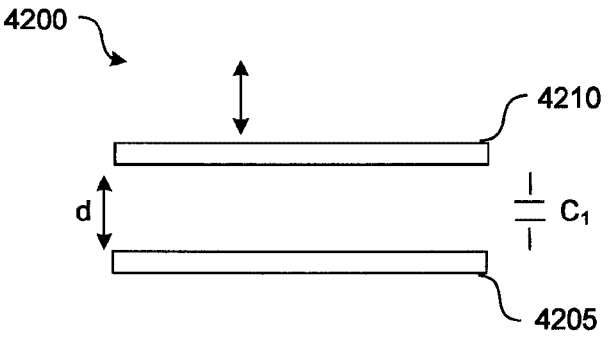


FIG. 42A-L

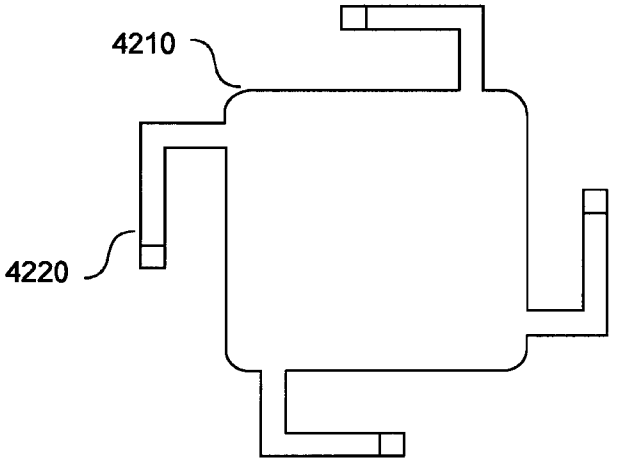


FIG. 42B-L

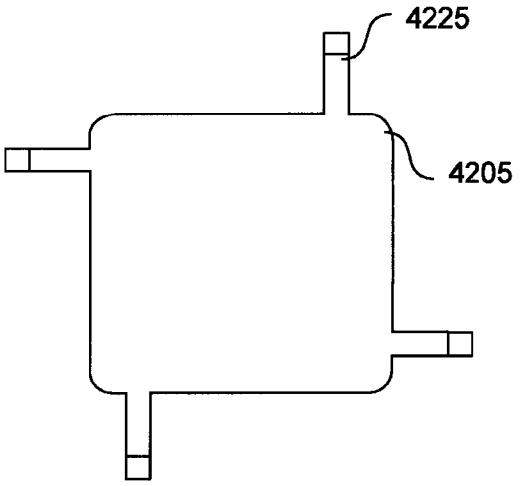


FIG. 42C-L

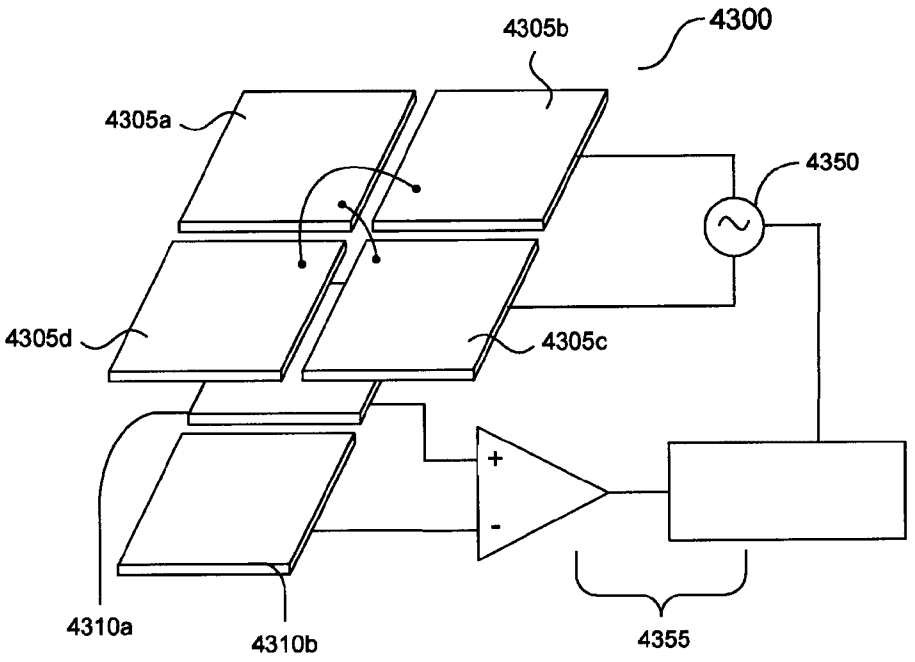


FIG. 43-L

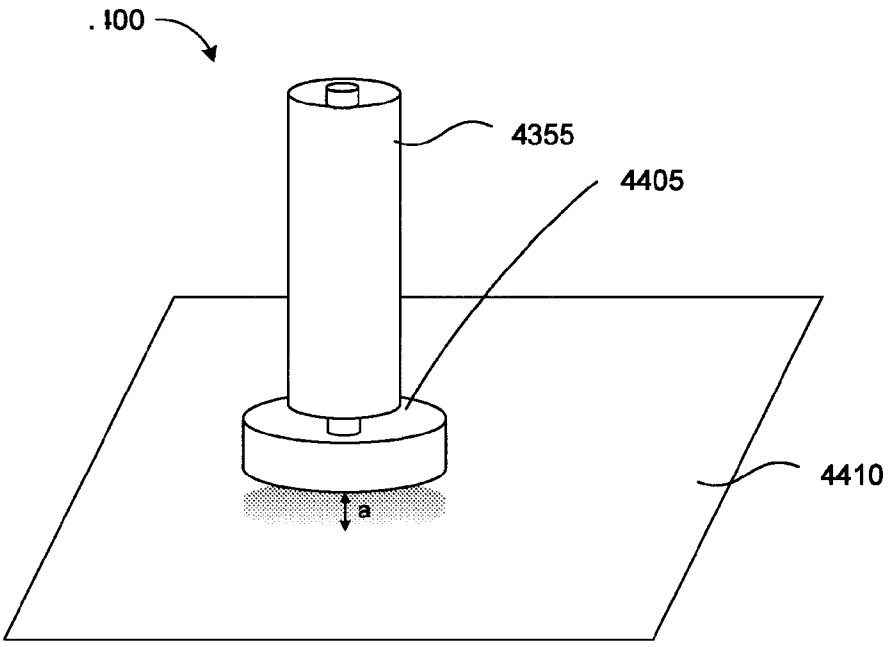


FIG. 44-L

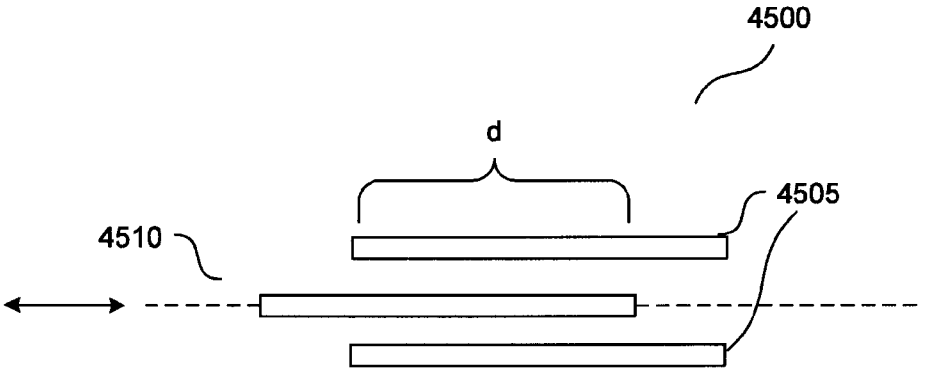


FIG. 45-L

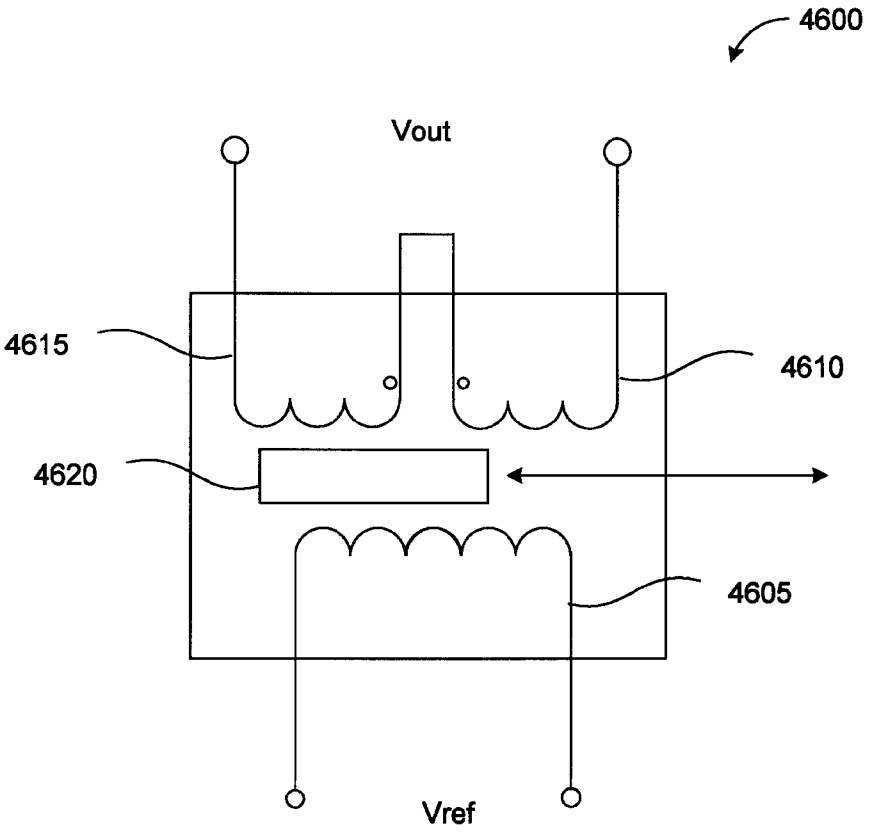


FIG. 46A-L

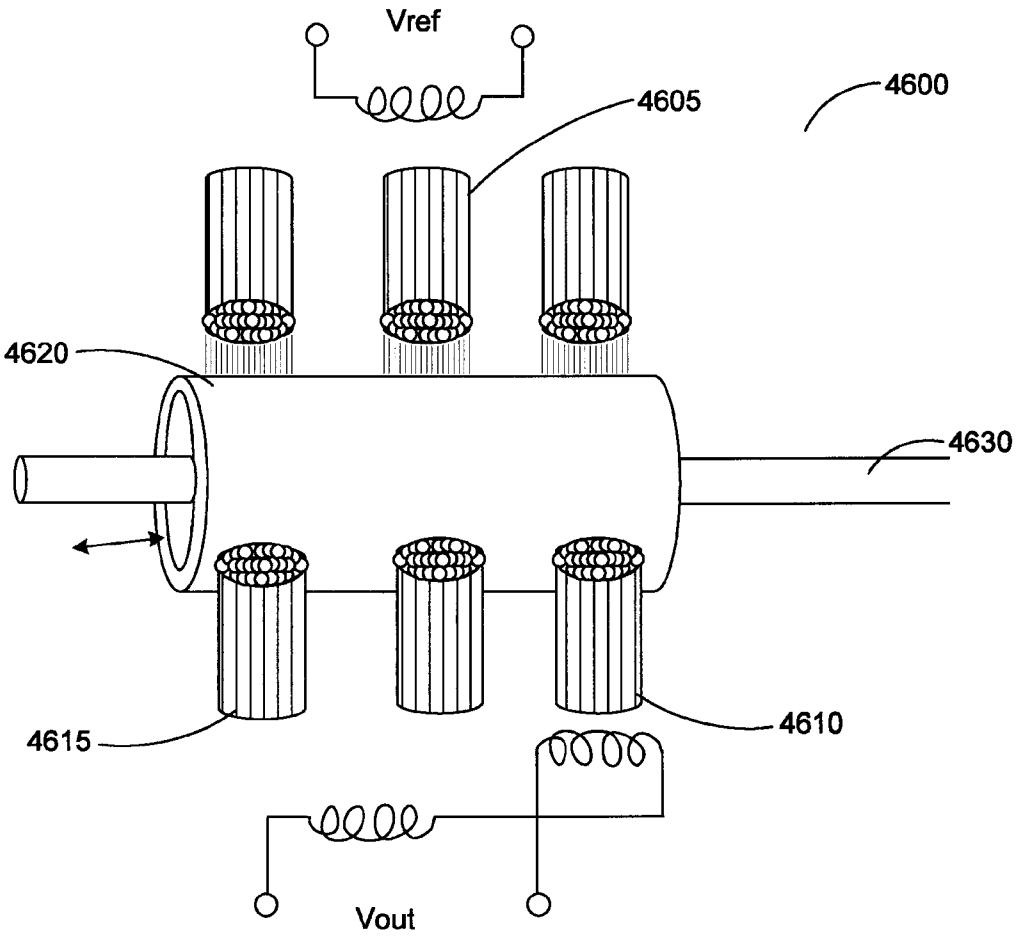


FIG. 46B-L

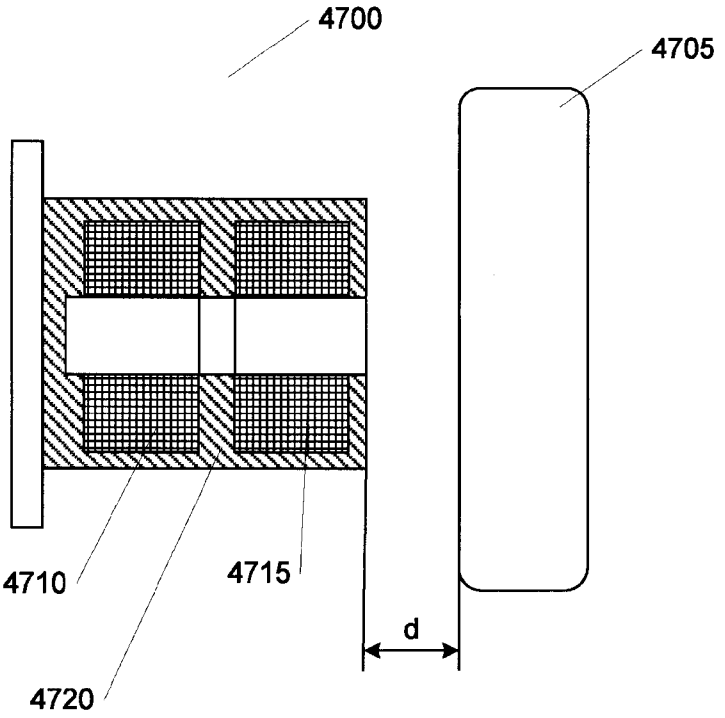


FIG. 47-L

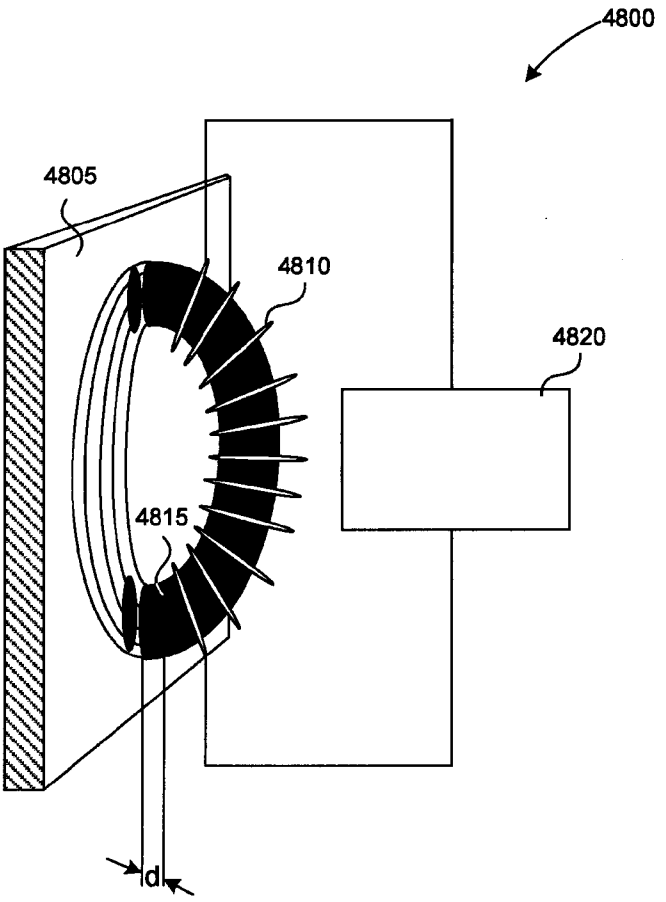


FIG. 48-L

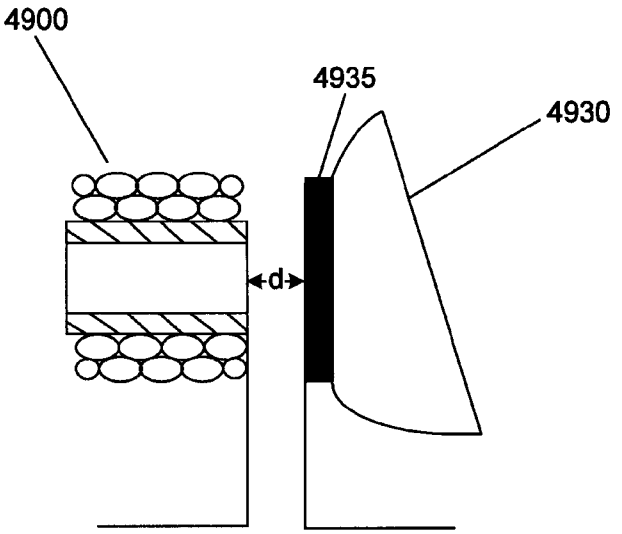


FIG. 49-L

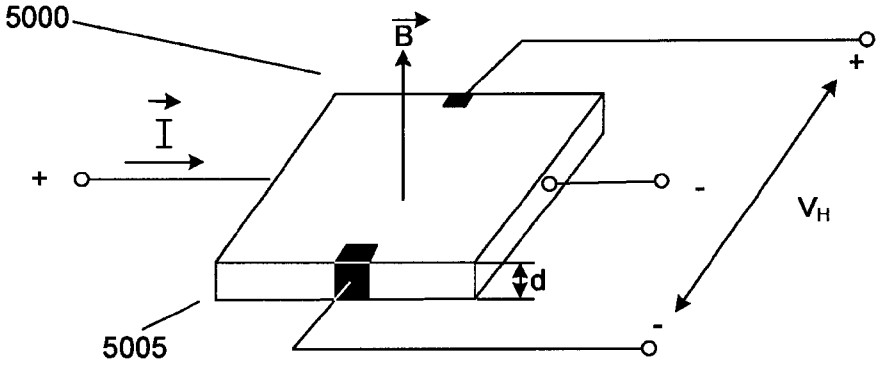


FIG. 50-L

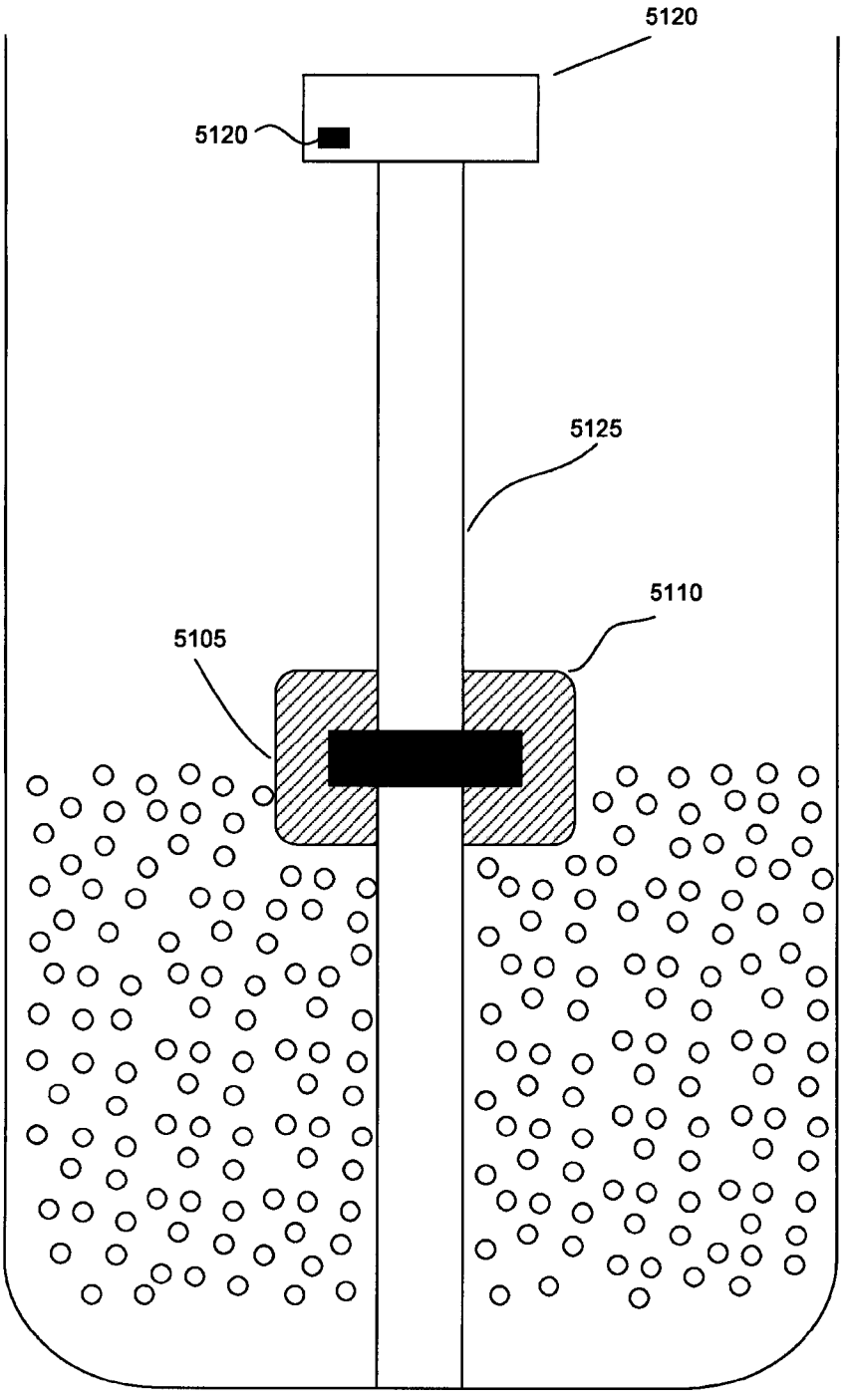


FIG. 51-L

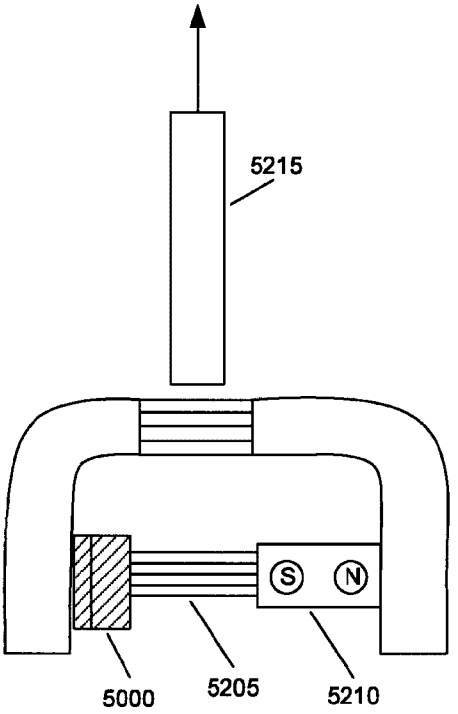


FIG. 52A-L

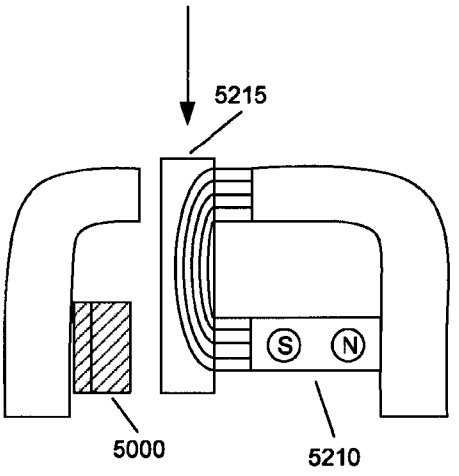


FIG. 52B-L

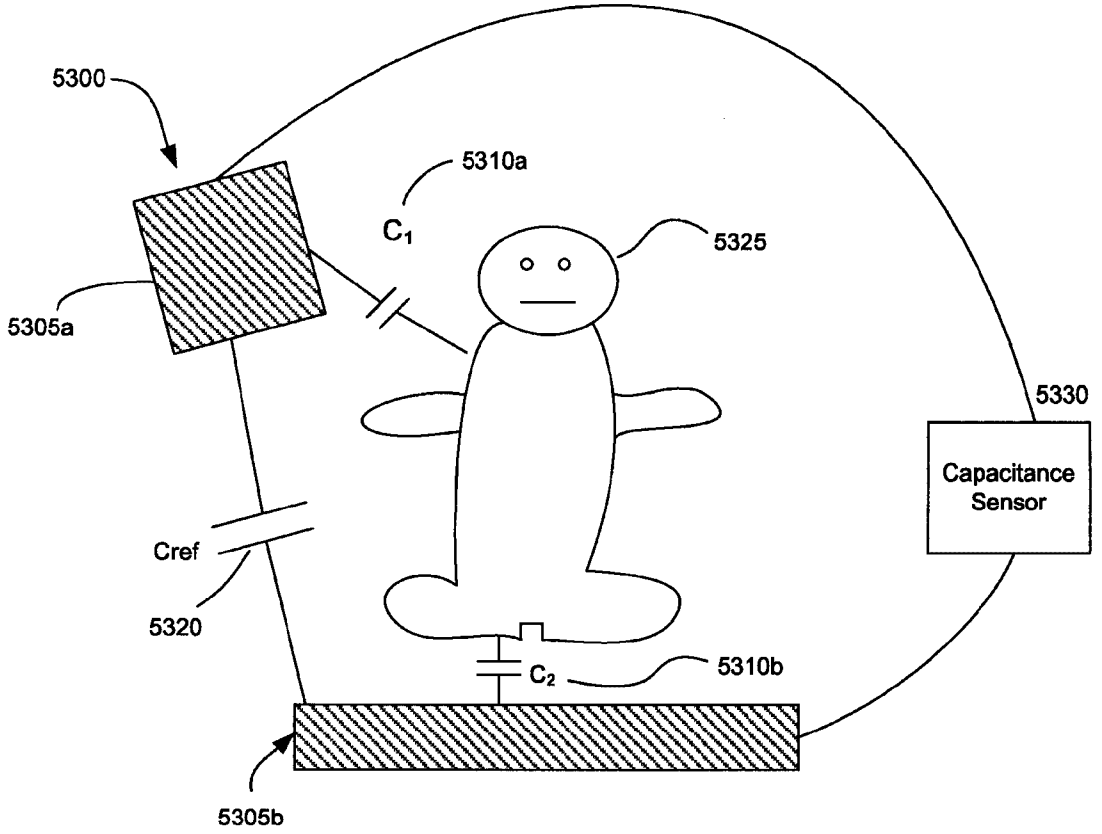

5300
5310a
C1
5325
5305a
5330
Capacitance Sensor
Cref
5320
C2
5310b
5305b

FIG. 53-L

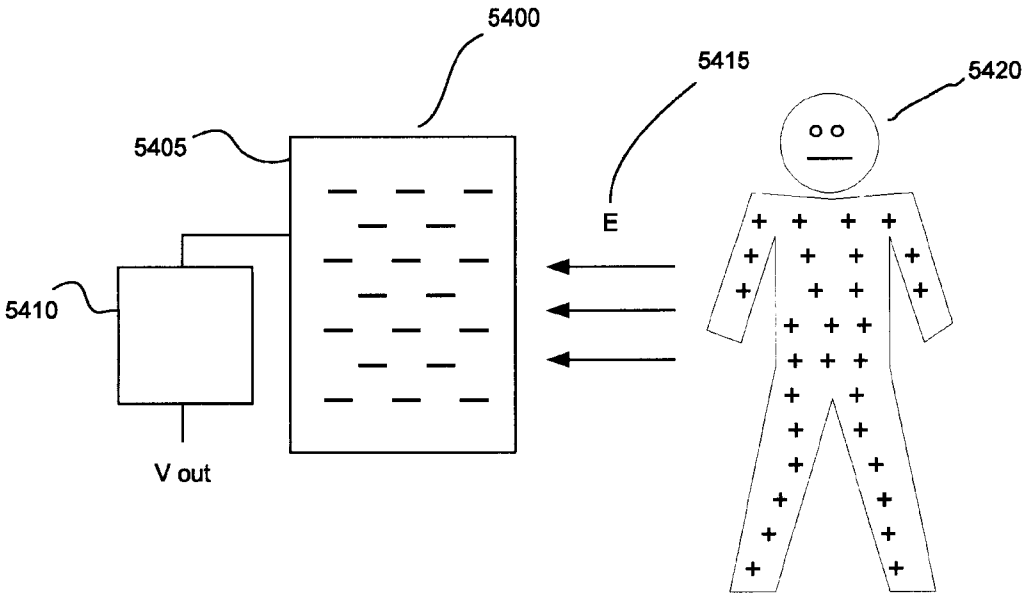


FIG. 54-L

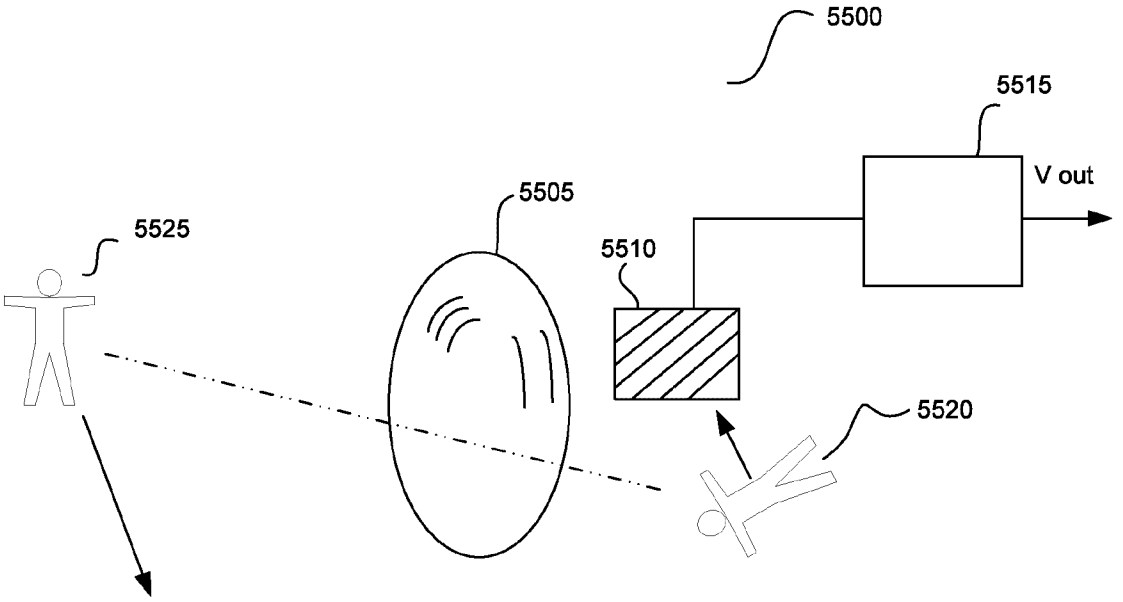


FIG. 55-L

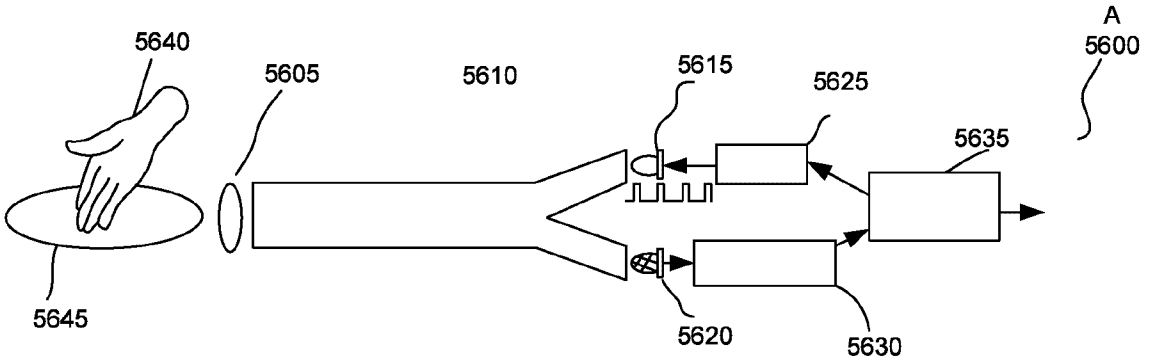


FIG. 56-L

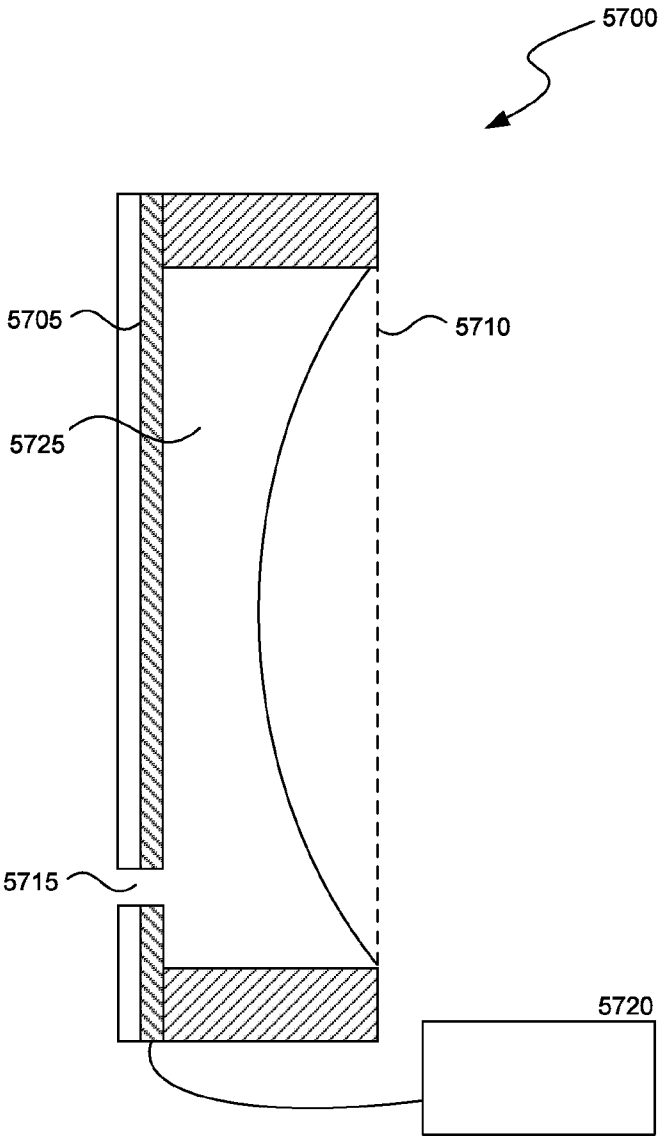


FIG. 57-L

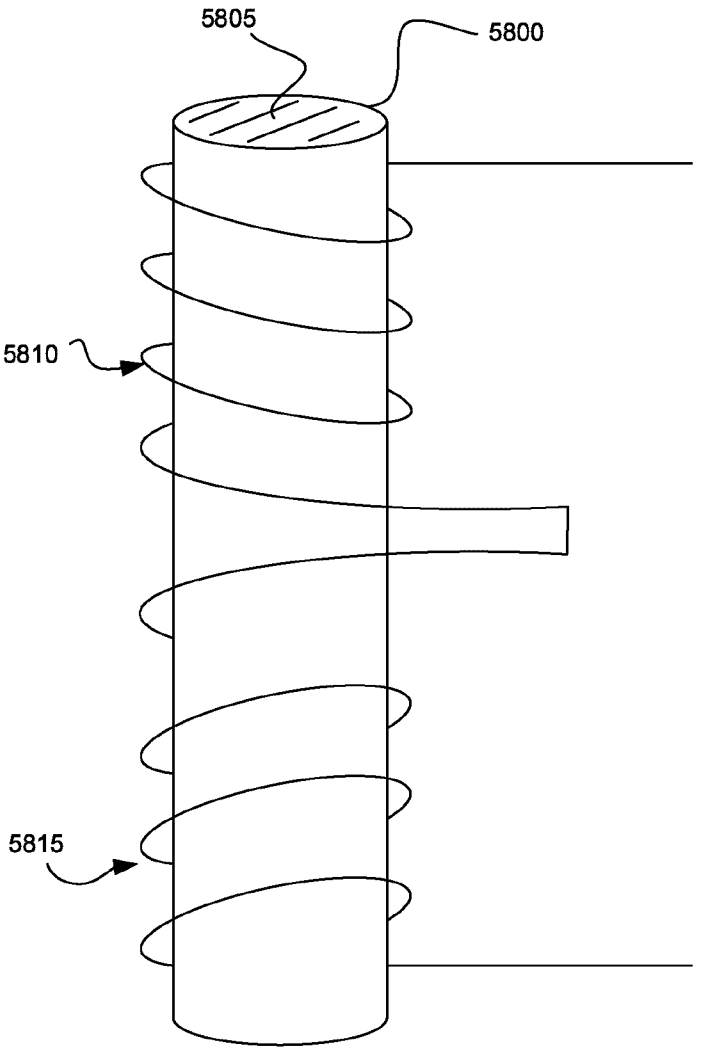


FIG. 58-L

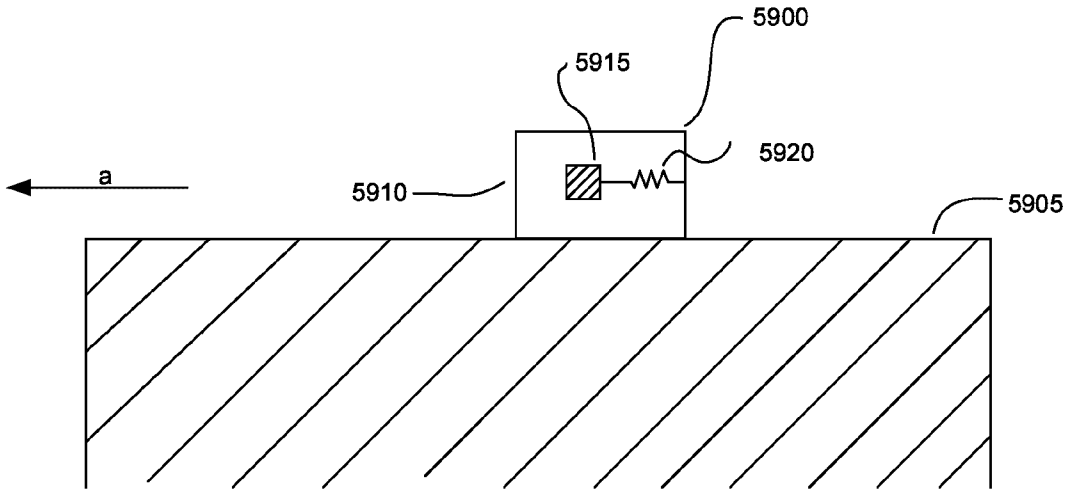


FIG. 59-L

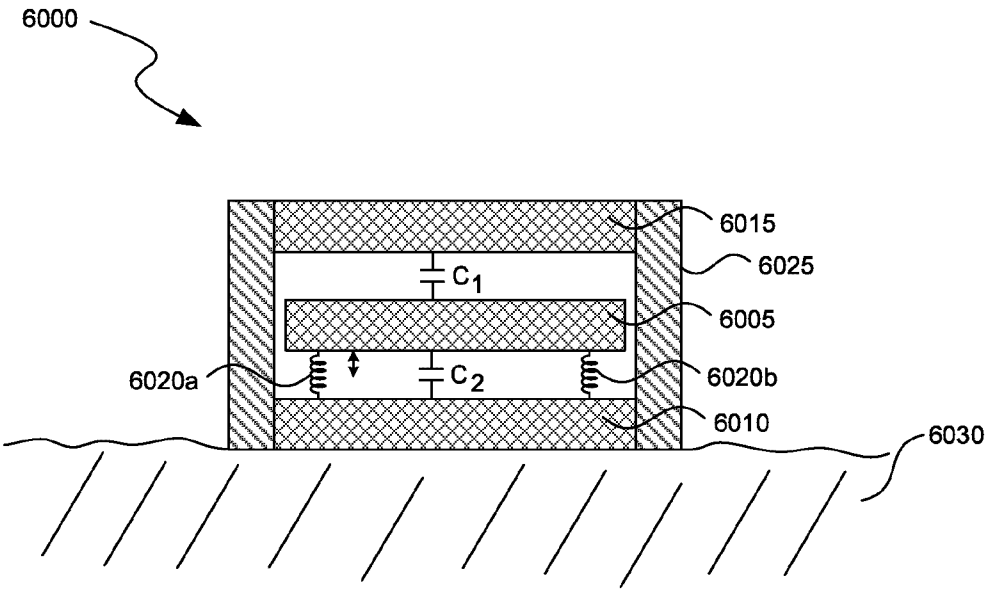


FIG. 60-L

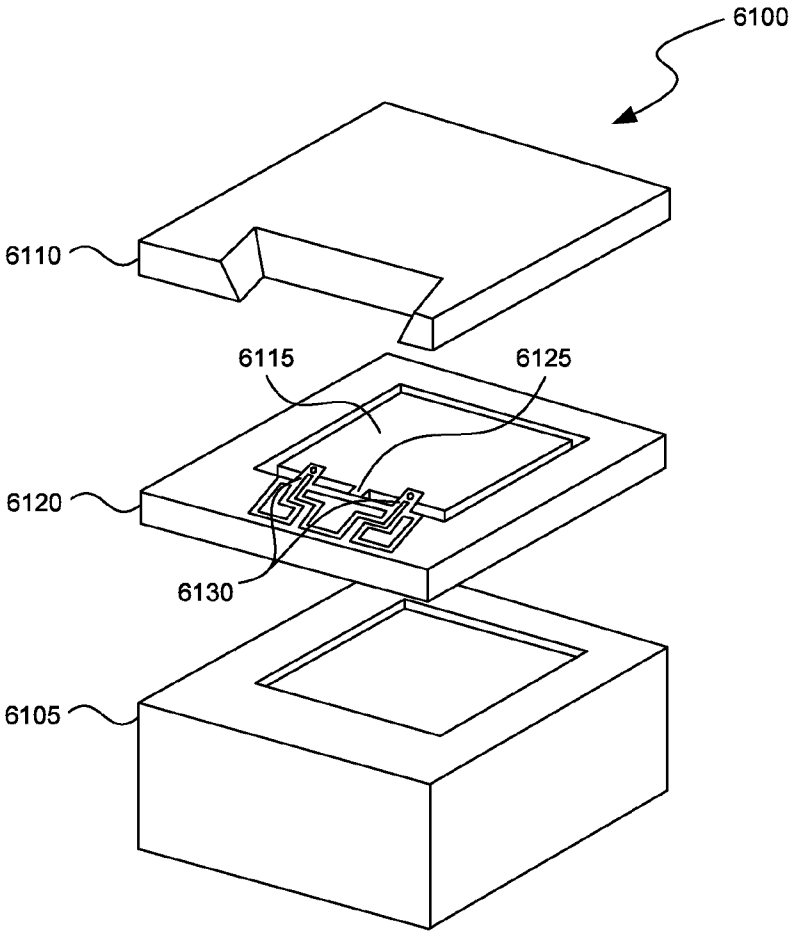


FIG. 61-L

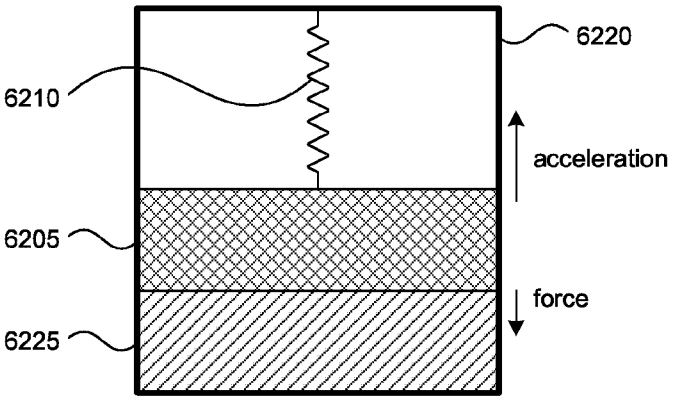


FIG. 62-L

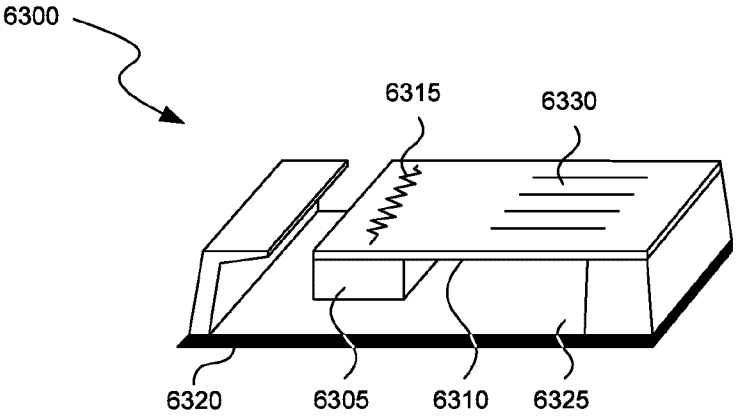


FIG. 63-L

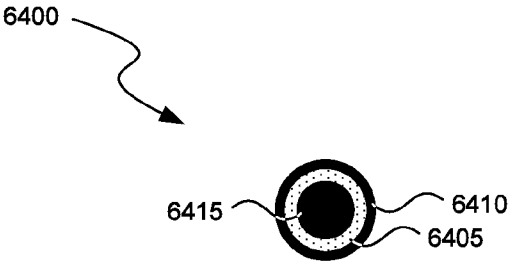


FIG. 64-L

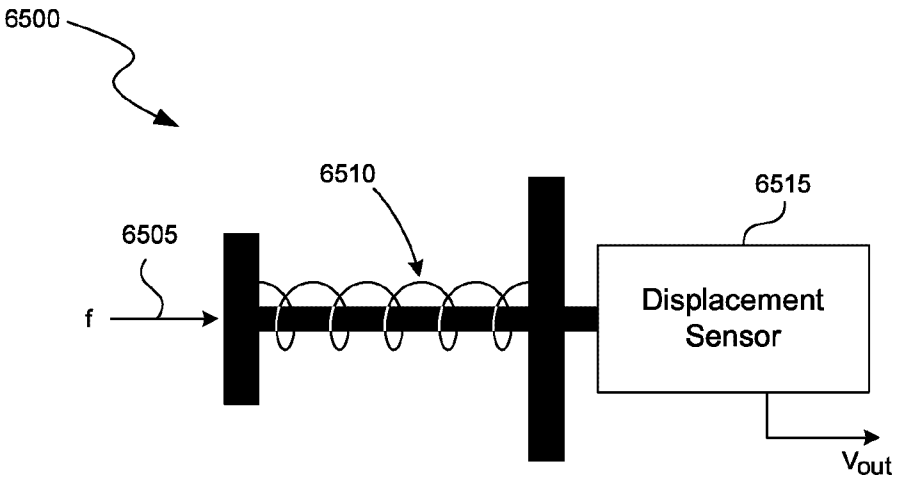


FIG. 65A-L

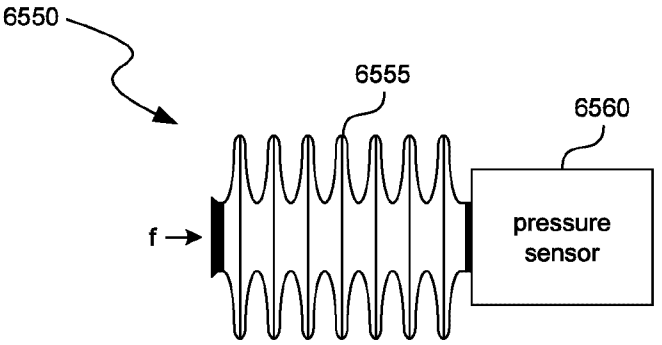


FIG. 65B-L

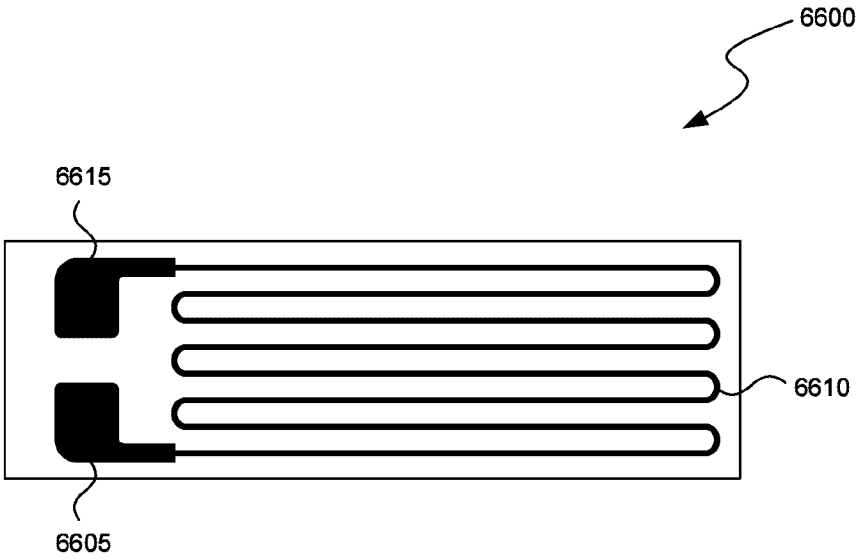


FIG. 66-L

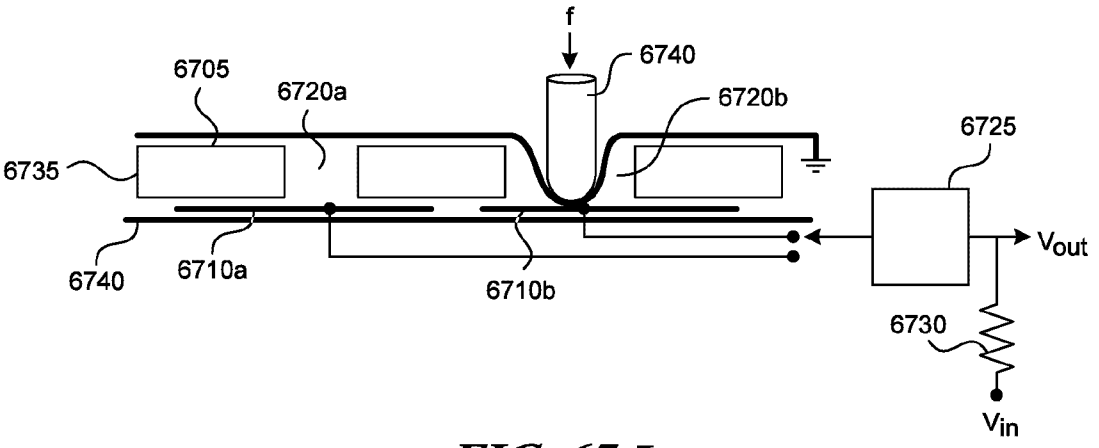

f
6740
6705
6720a
6720b
6725
6735
6740
6710a
6710b
Vout
6730
Vin

FIG. 67-L

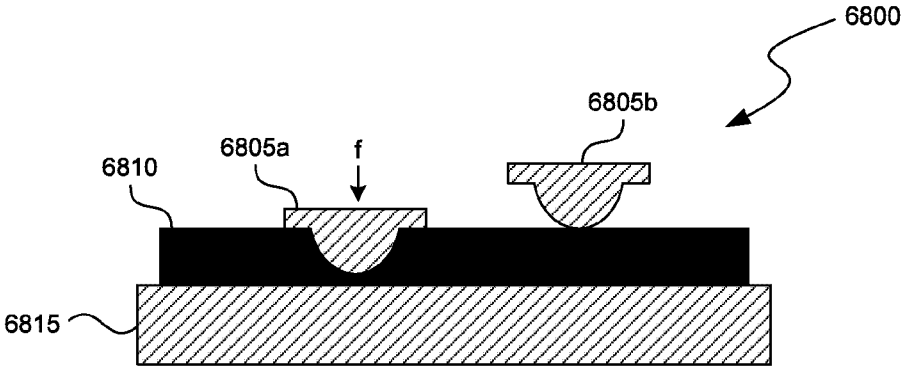


FIG. 68-L

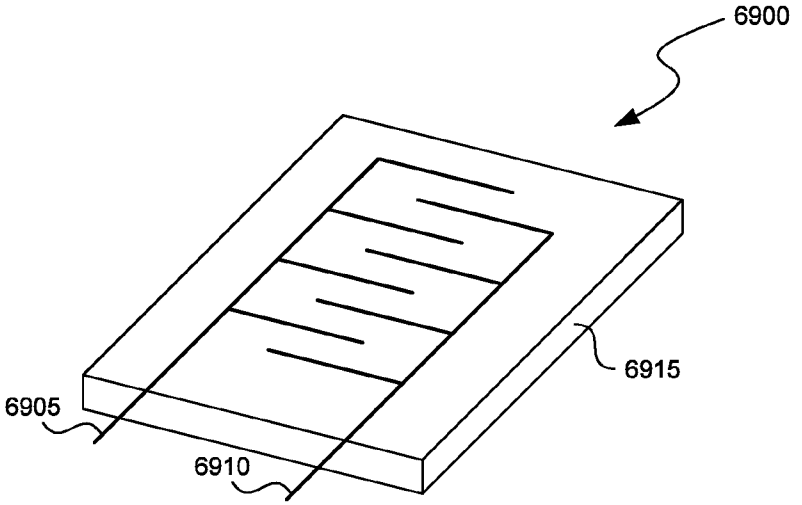


FIG. 69-L

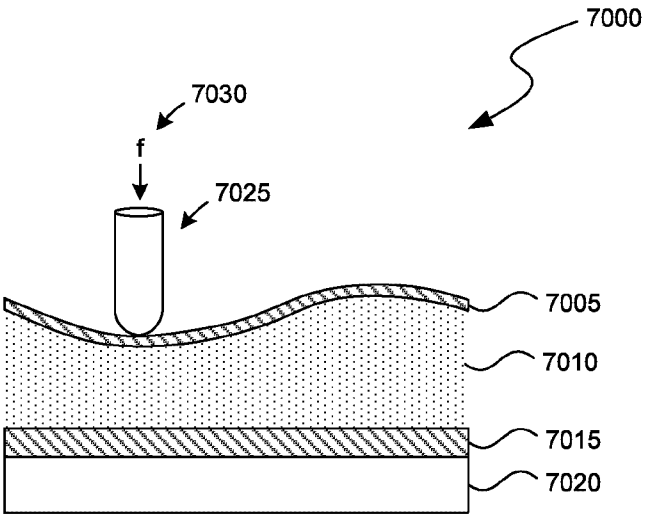


FIG. 70-L

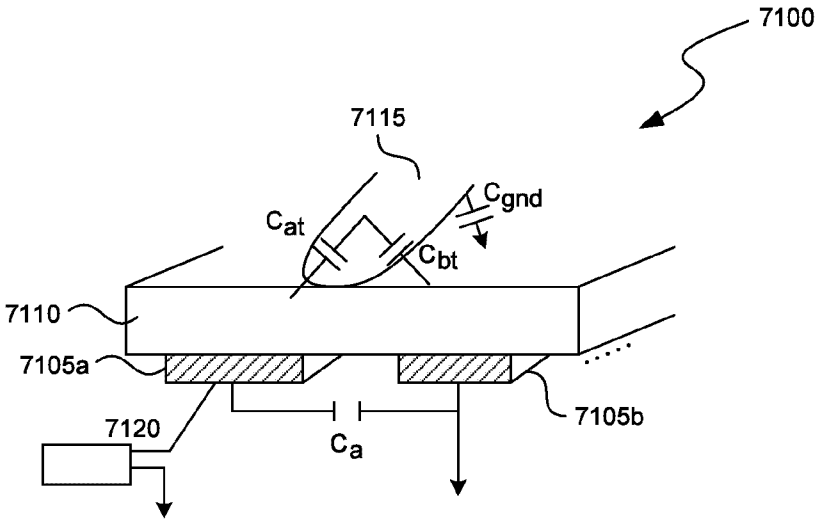


FIG. 71A-L

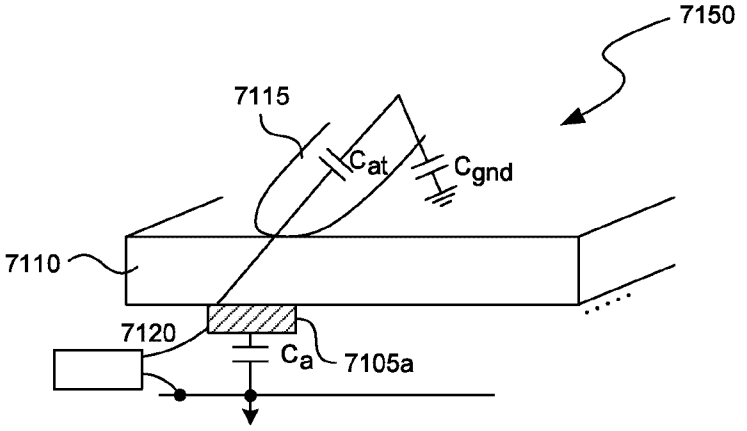


FIG. 71B-L

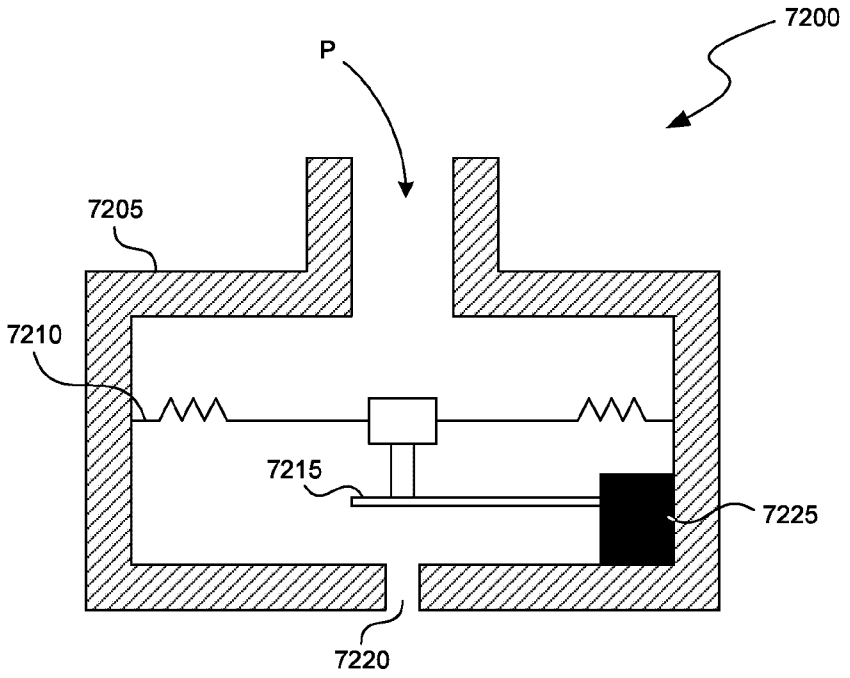


FIG. 72-L

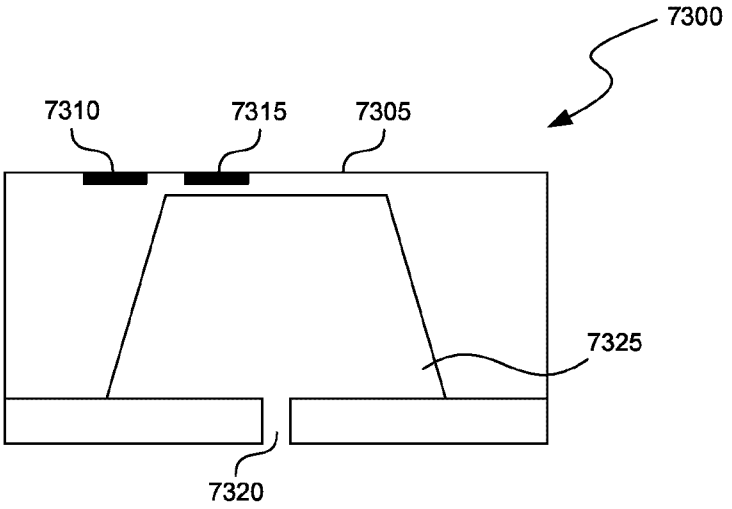


FIG. 73-L

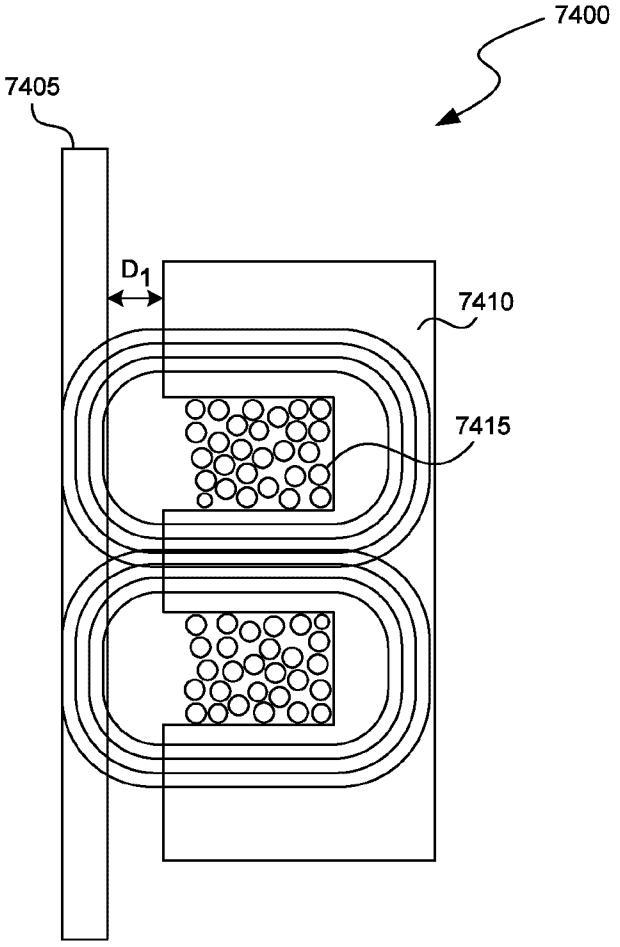


FIG. 74A-L

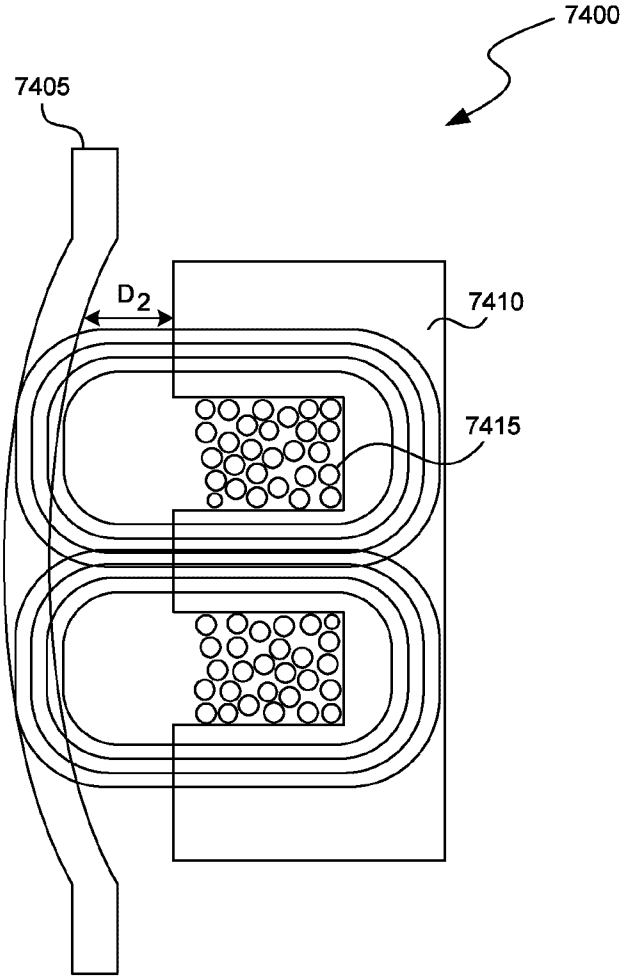


FIG. 74B-L

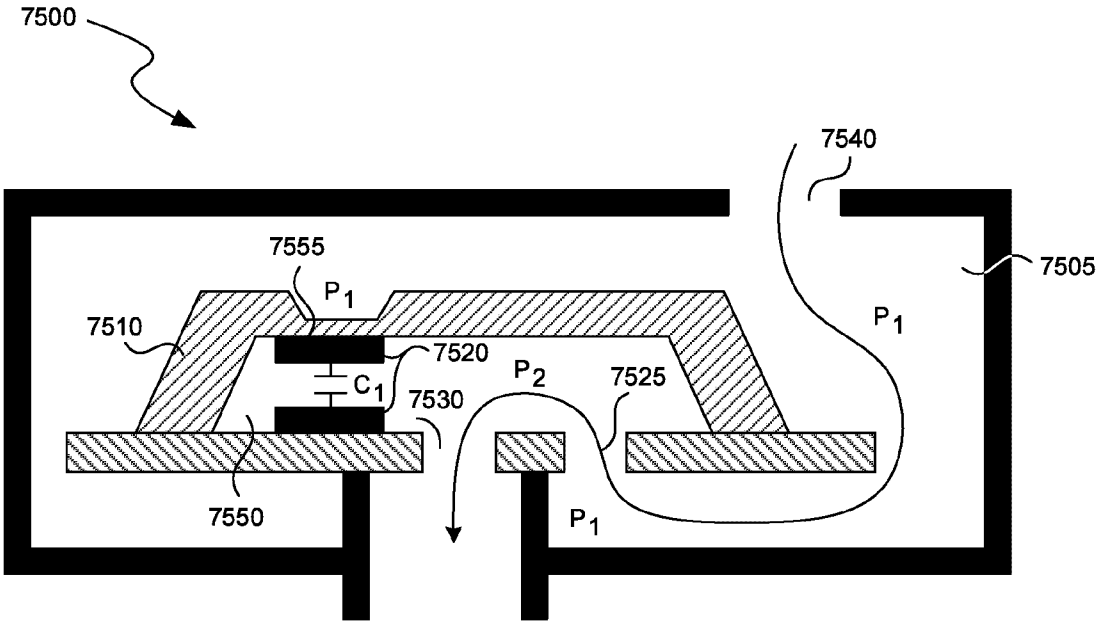


FIG. 75-L

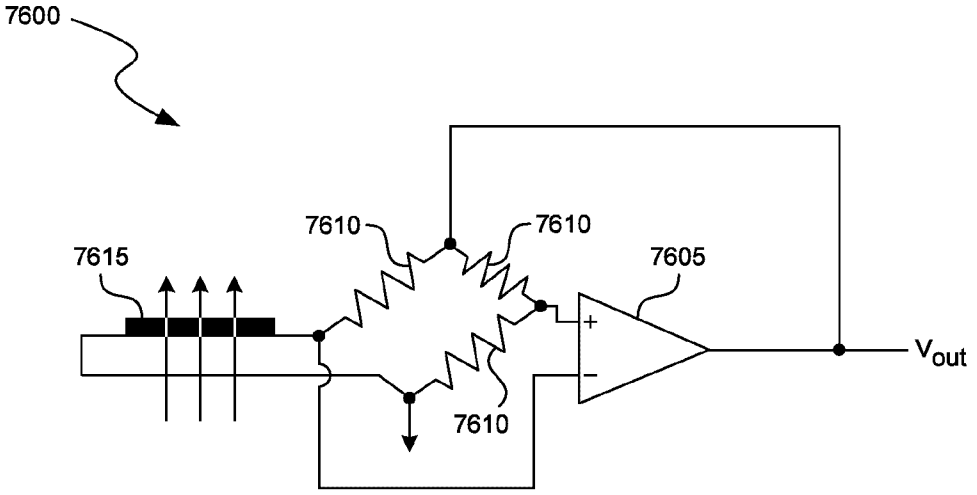


FIG. 76-L

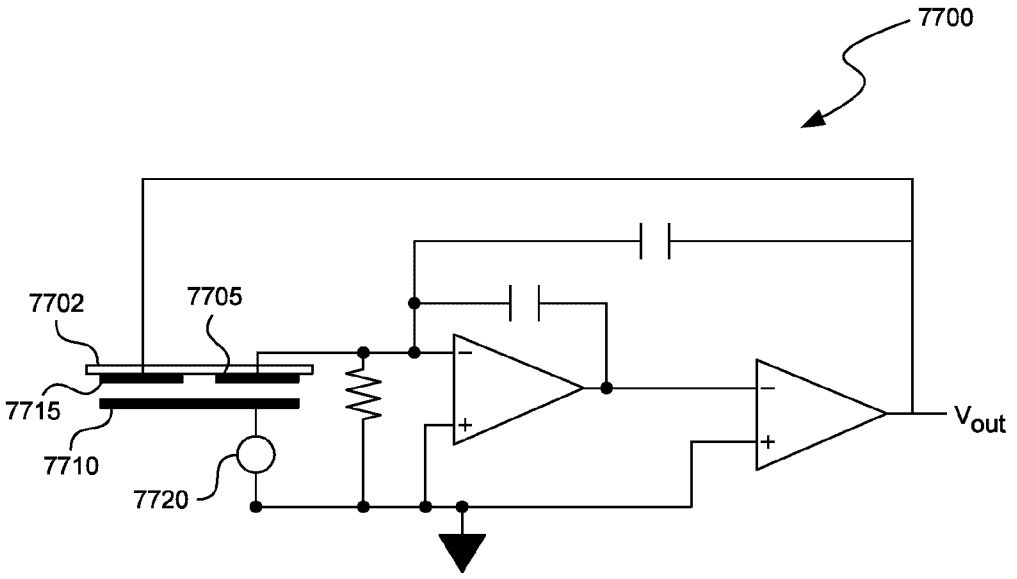


FIG. 77-L

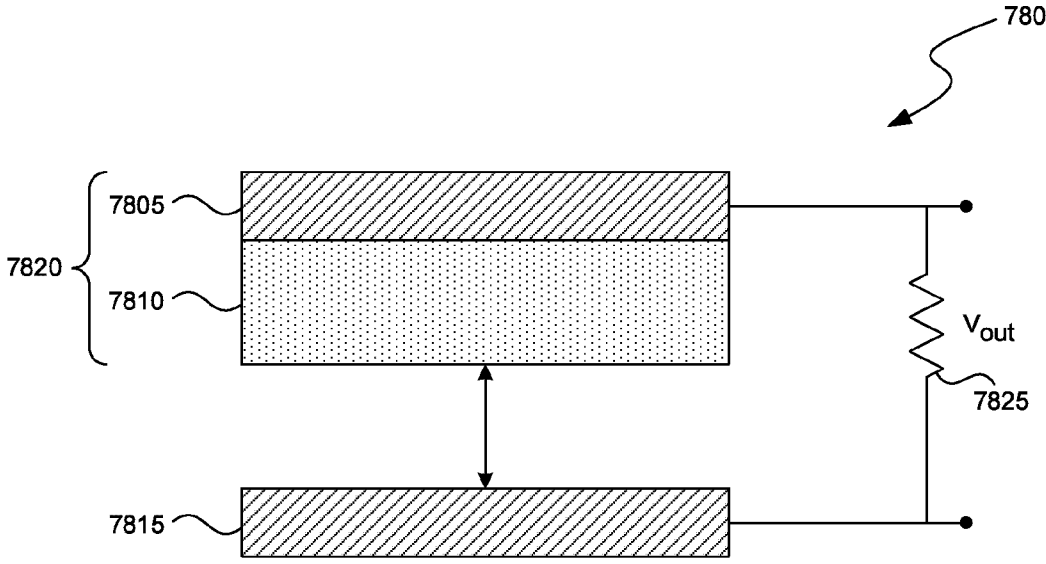


FIG. 78-L

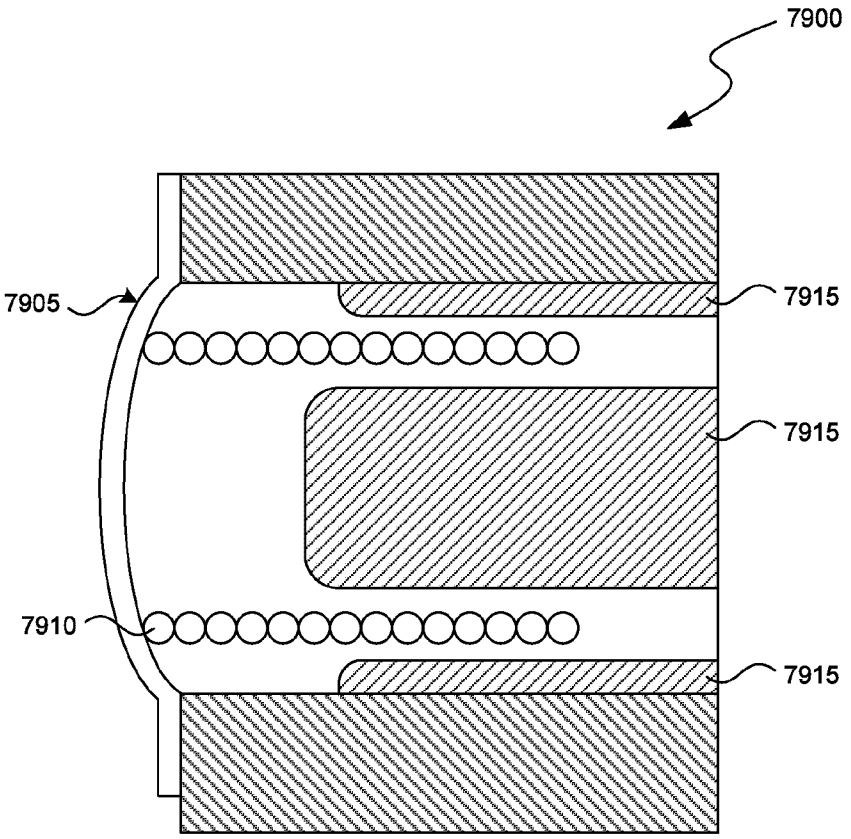


FIG. 79-L

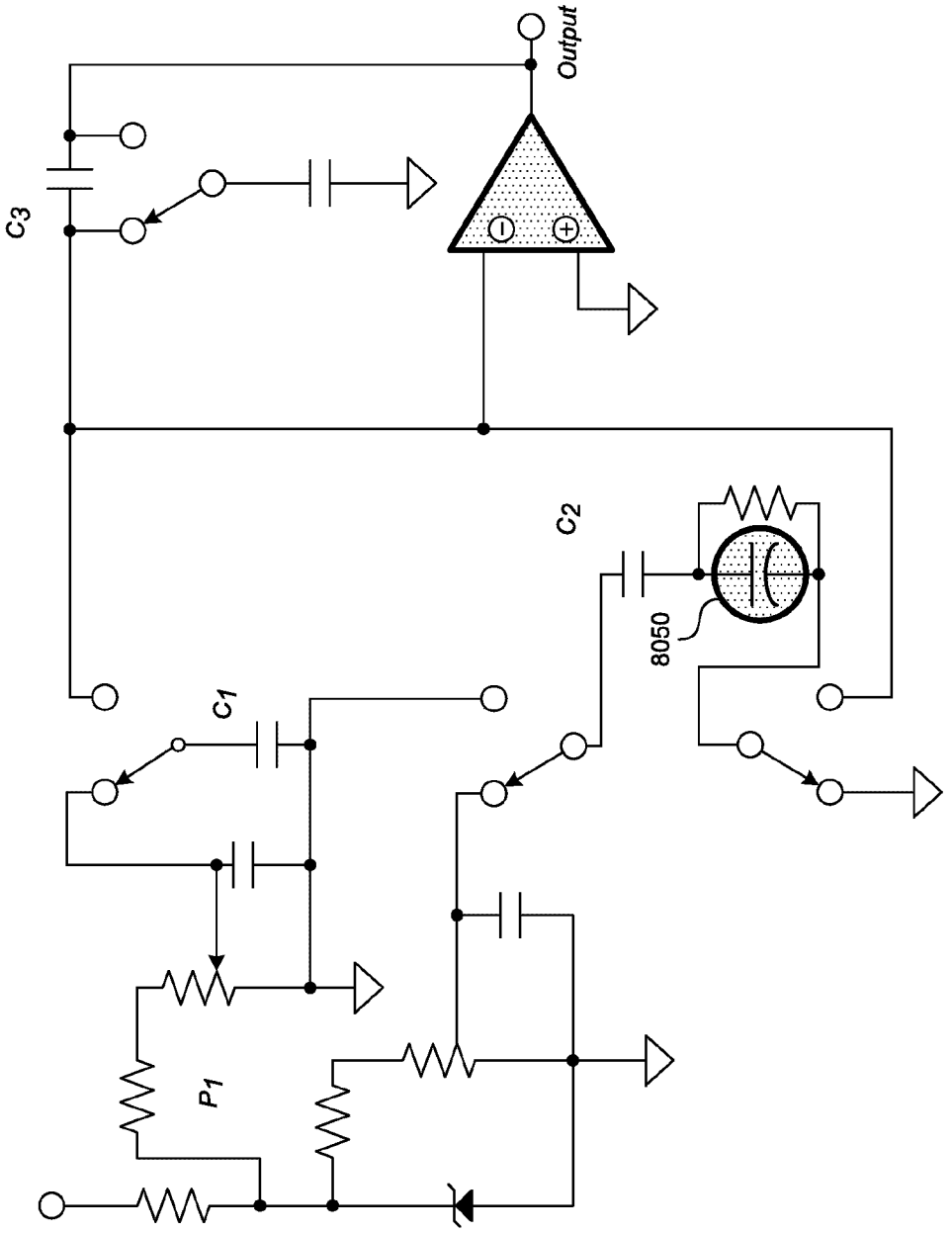


FIG. 80-L

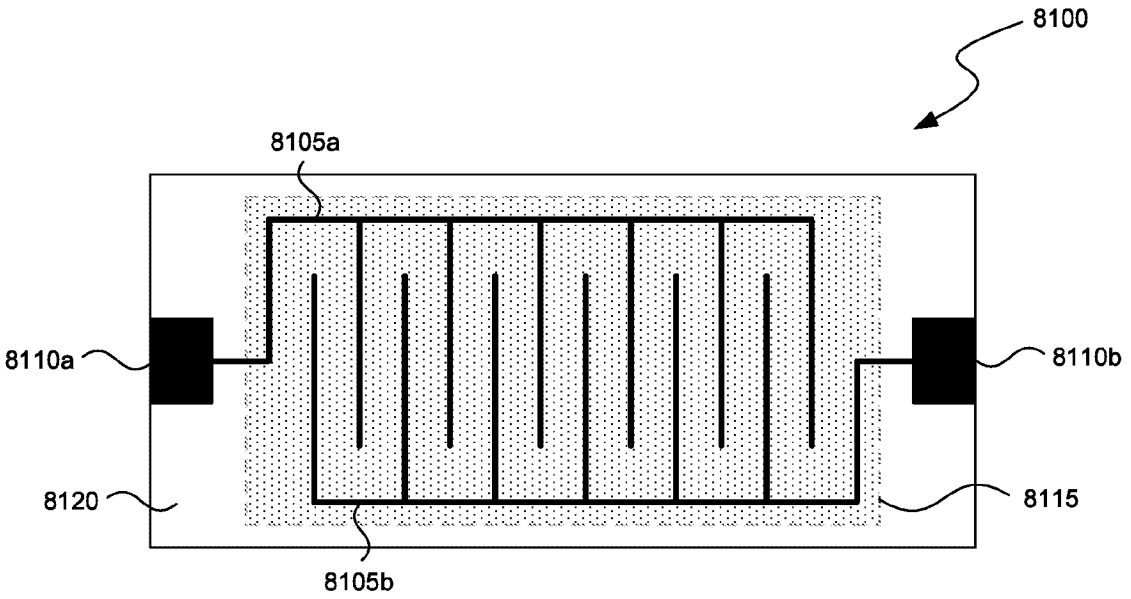


FIG. 81A-L

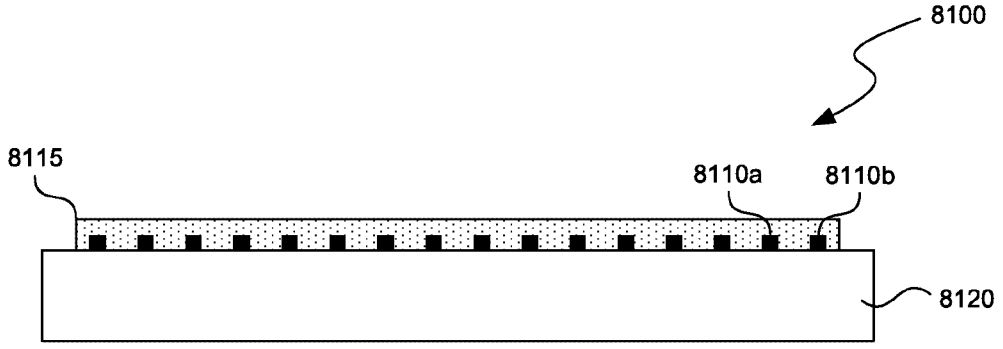


FIG. 81B-L

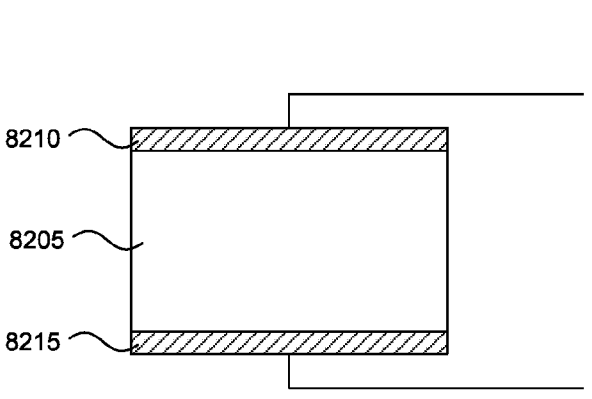


FIG. 82-L

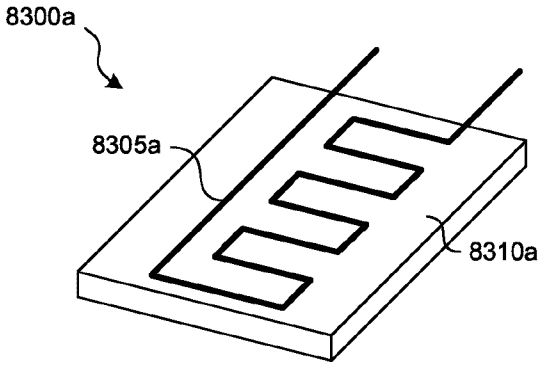


FIG. 83A-L

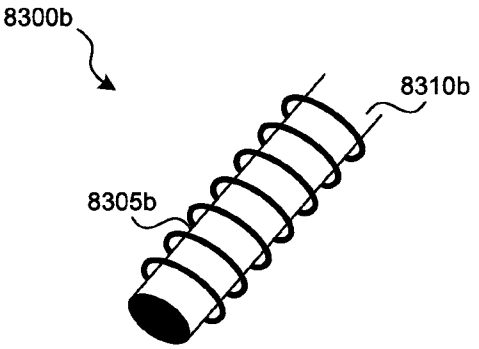


FIG. 83B-L

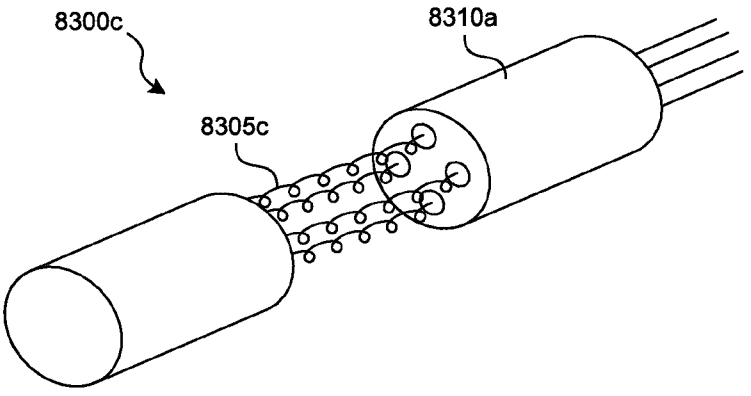


FIG. 83C-L

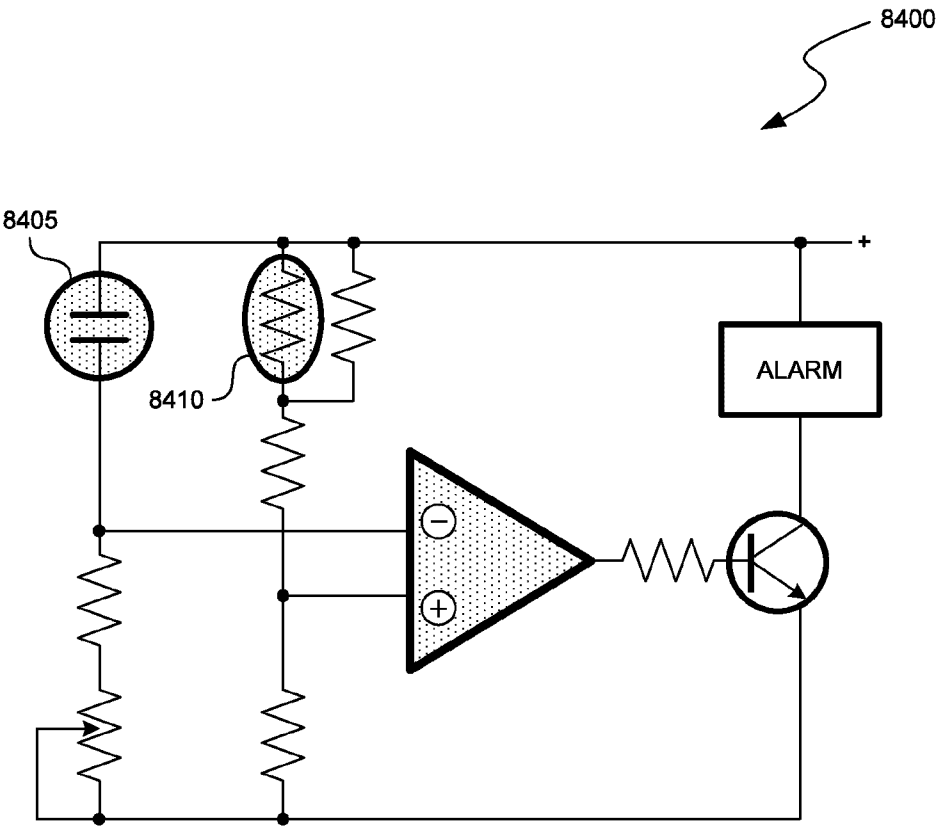


FIG. 84-L

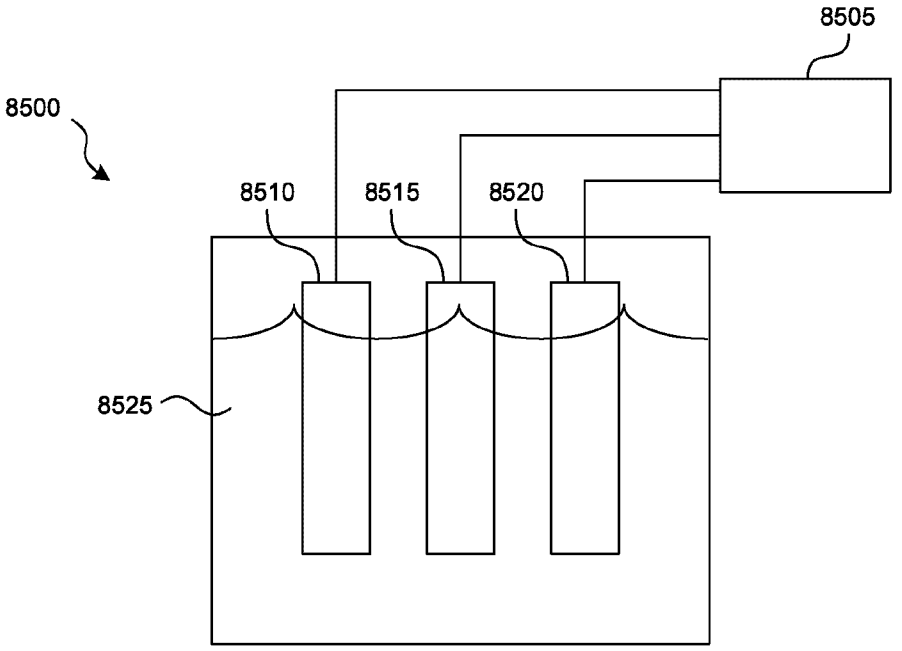


FIG. 85-L

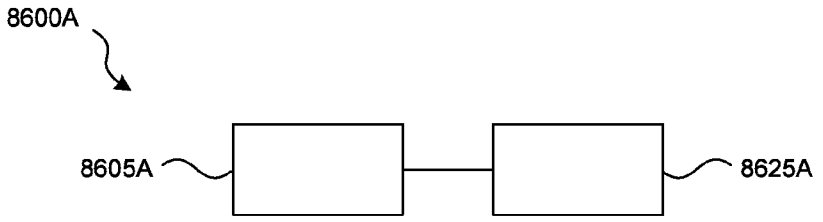


FIG. 86A-L

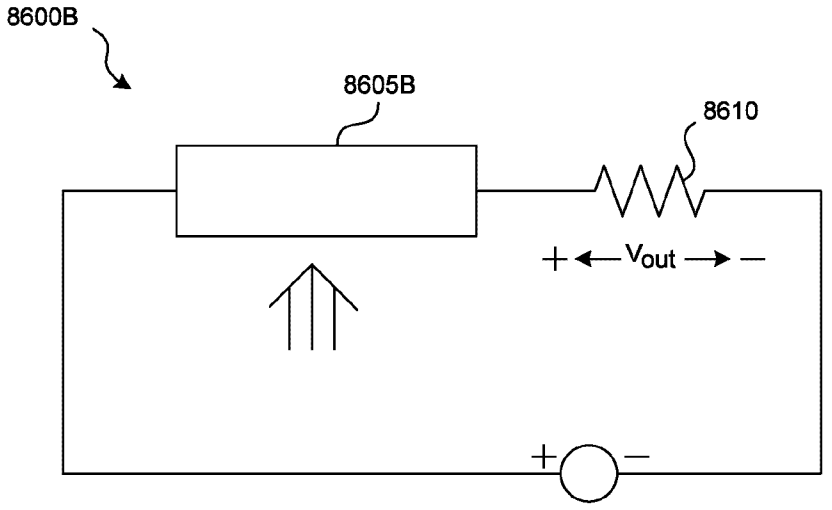


FIG. 86B-L

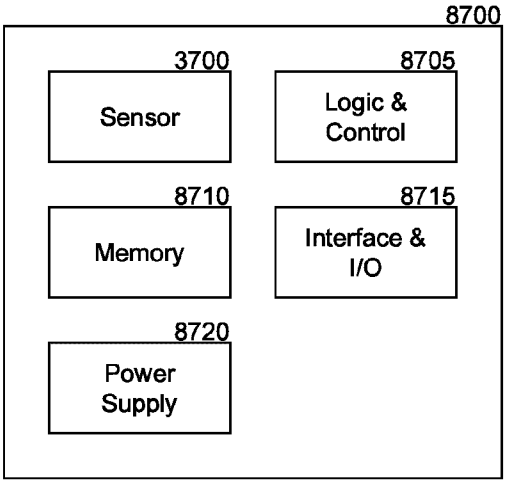


FIG. 87-L

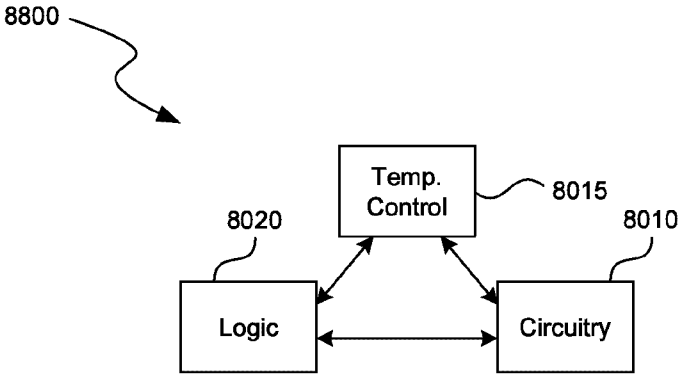


FIG. 88-L

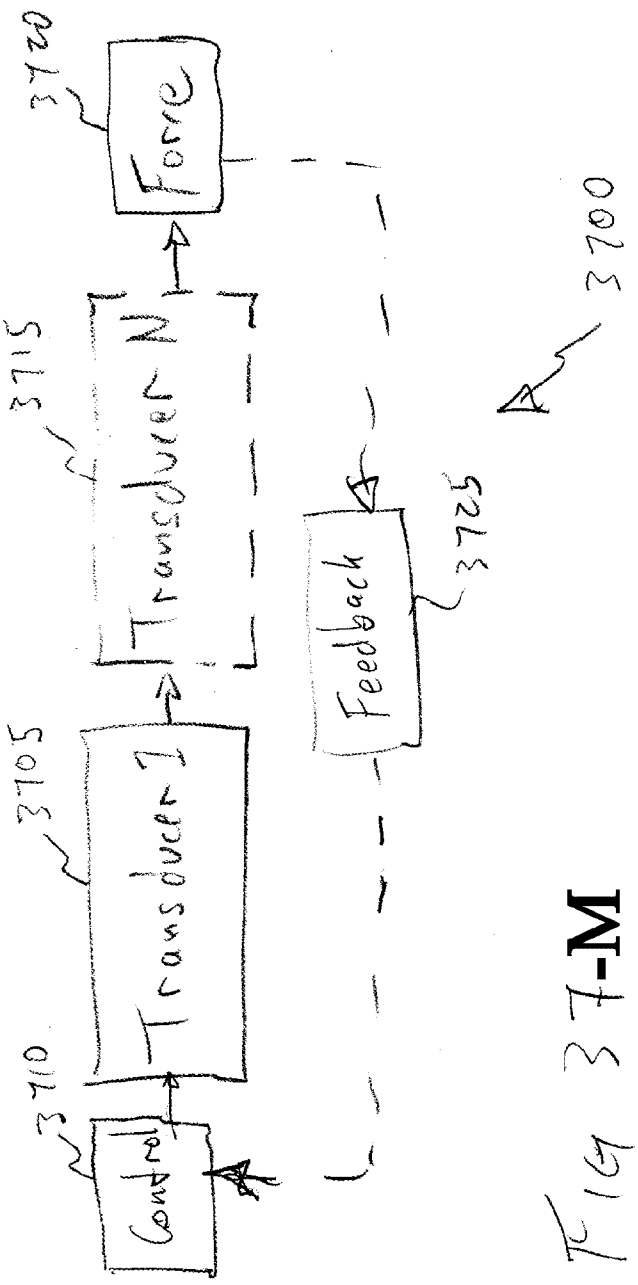


FIG 37-M

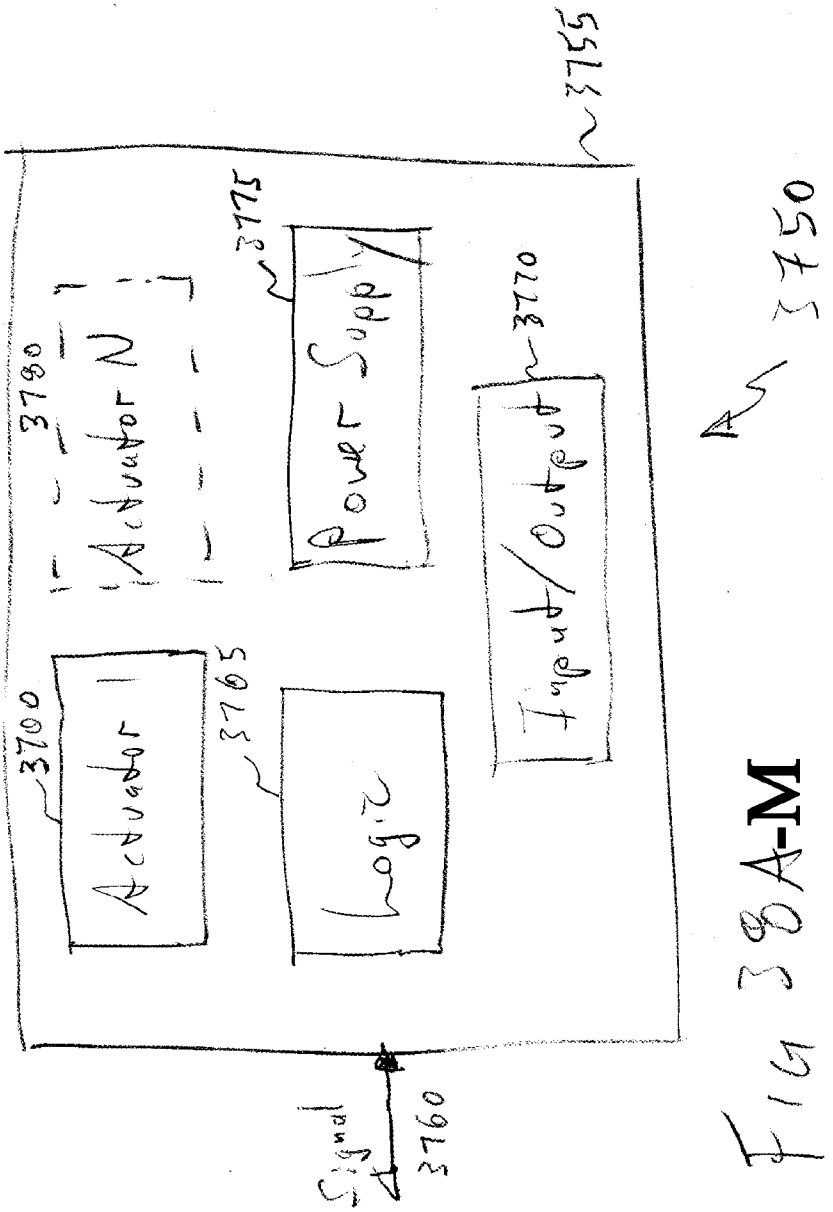

3755
3775
3790
Actuator N
3770
Power Supply
Input/Output
3700
Actuator 1
3765
Logic
Signal
3760
3750

FIG 38A-M

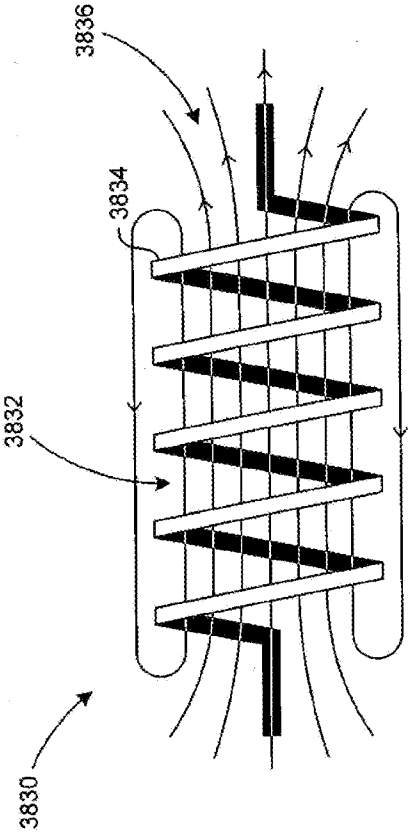


FIG. 38B-M

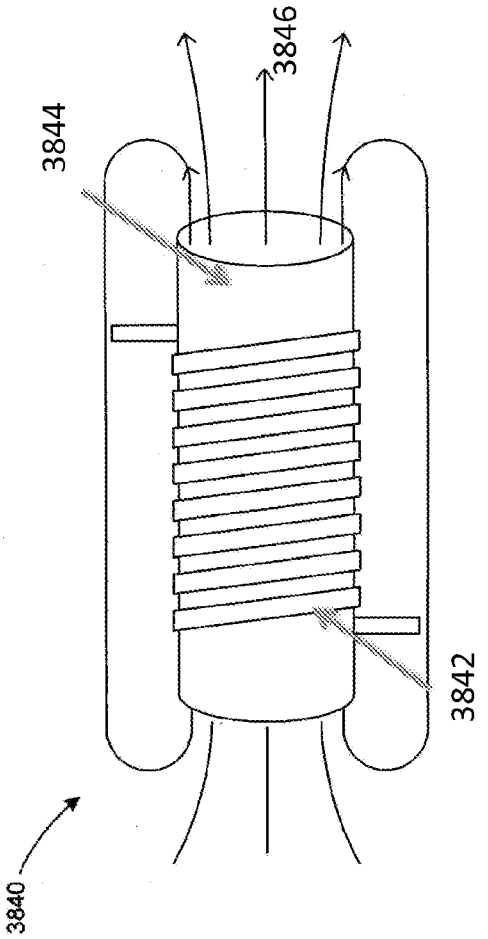


FIG. 38C-M

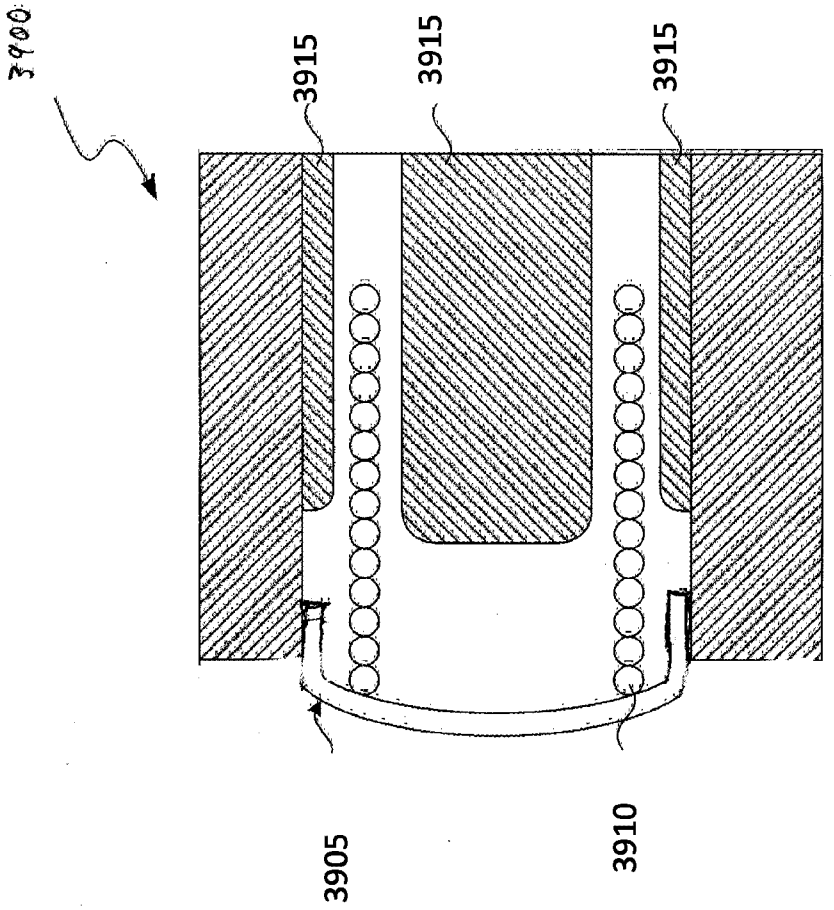


FIG. 39-M

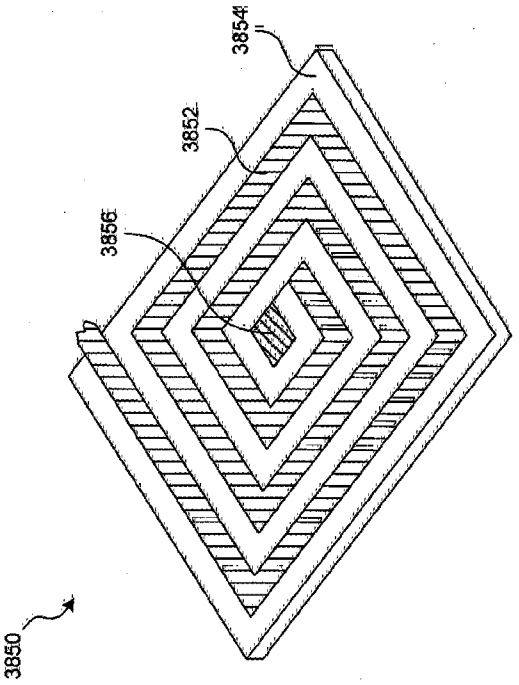


FIG. 38D-M

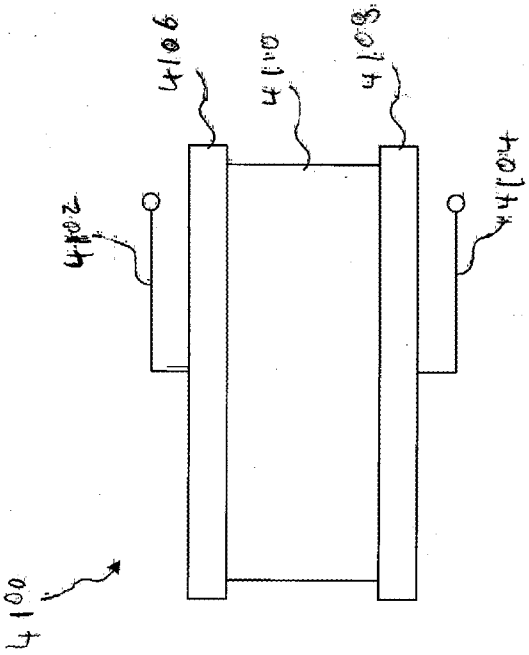


FIG. 41-M

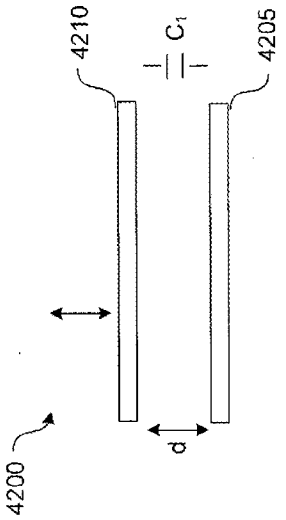


FIG. 42A-M

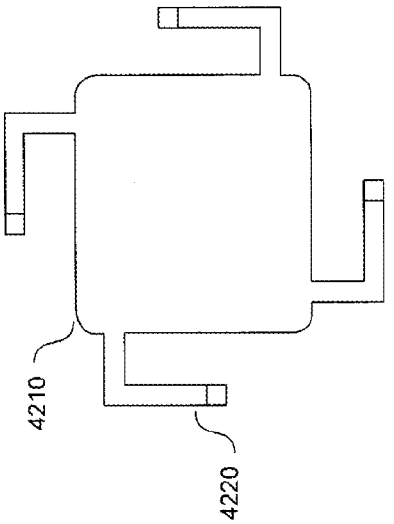


FIG. 42B-M

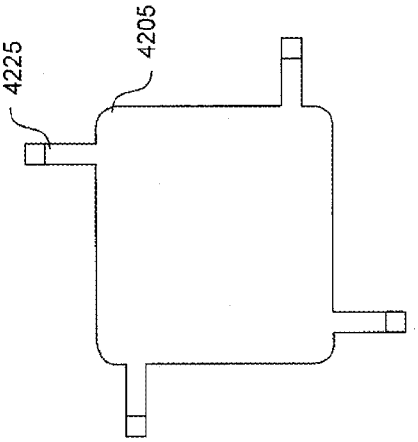


FIG. 42C-M

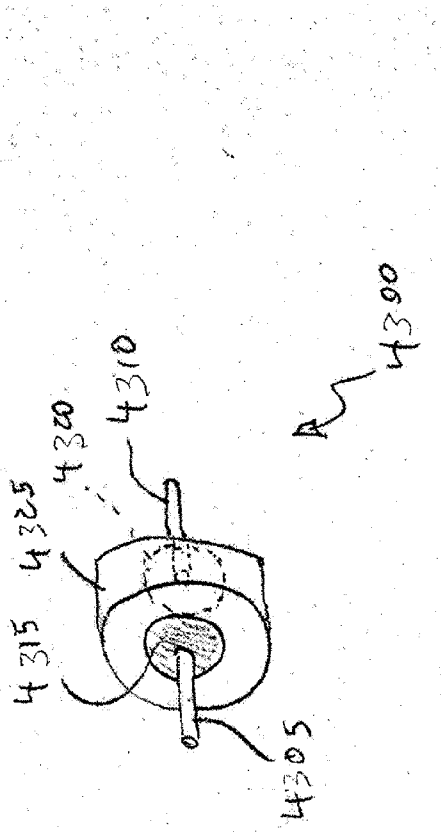


FIG. 43-M

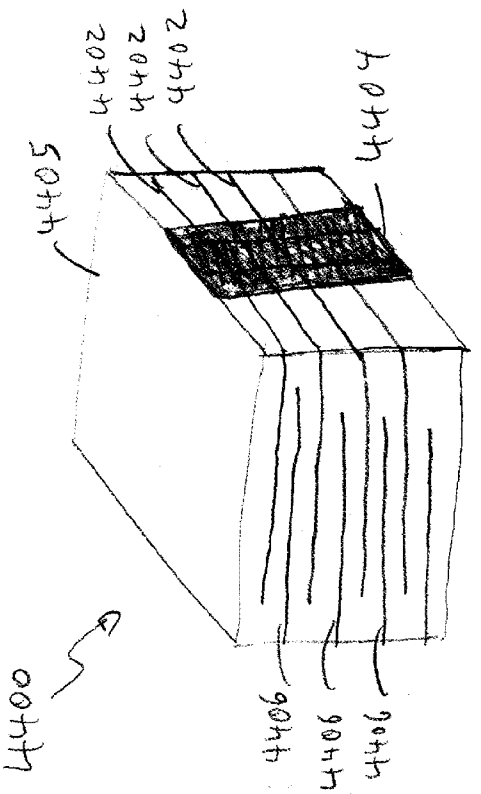


FIG. 44-M

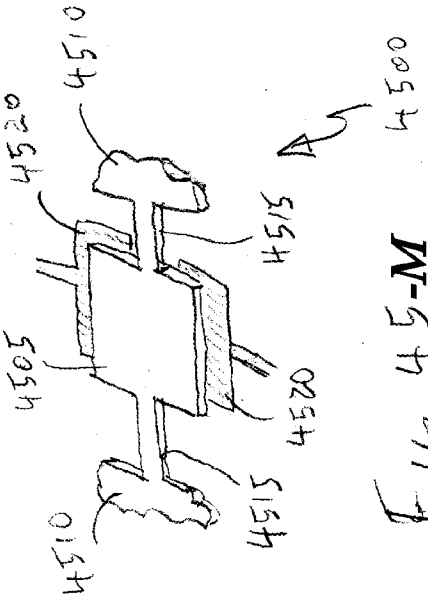


Fig 45-M

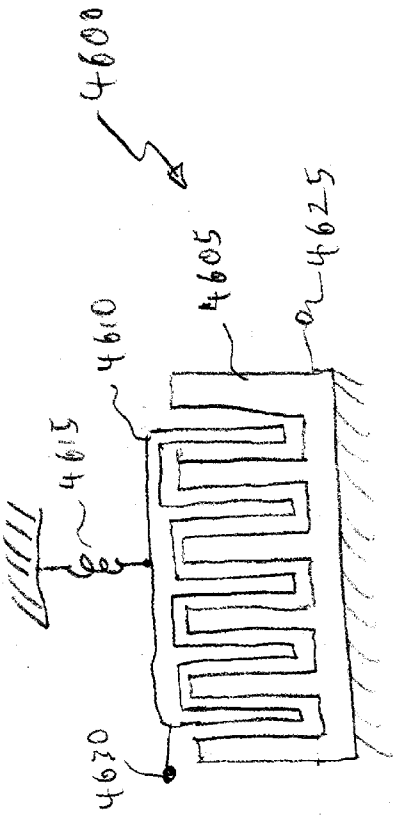


Fig 46-M

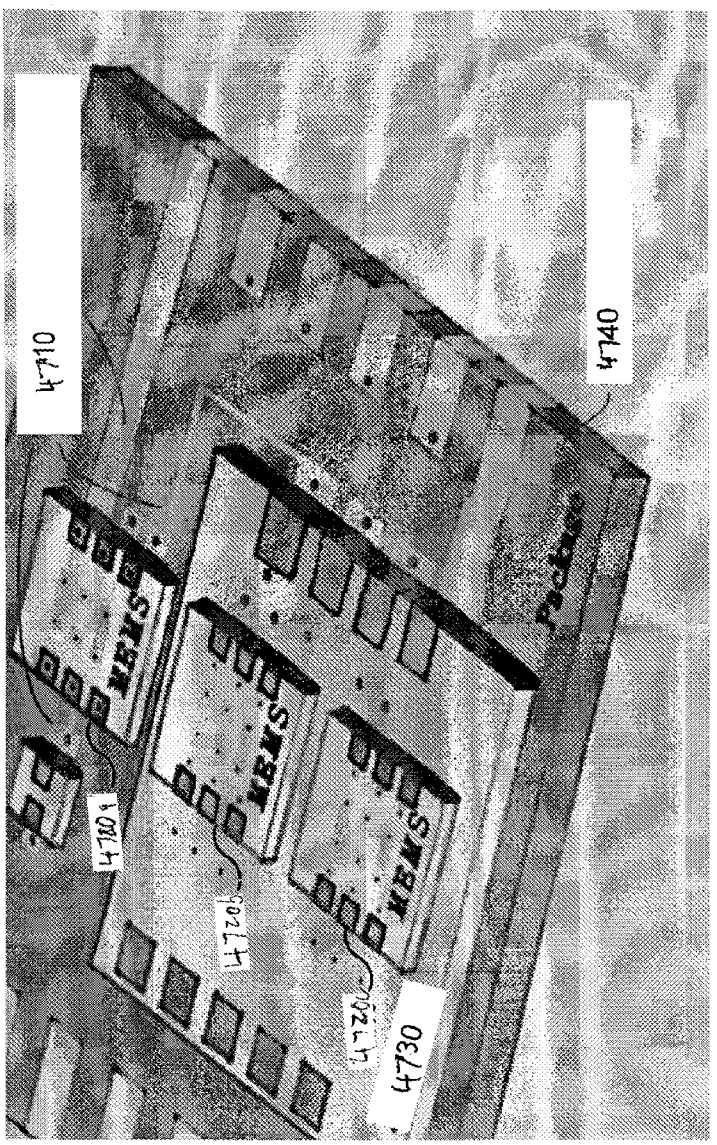


FIG. 47-M

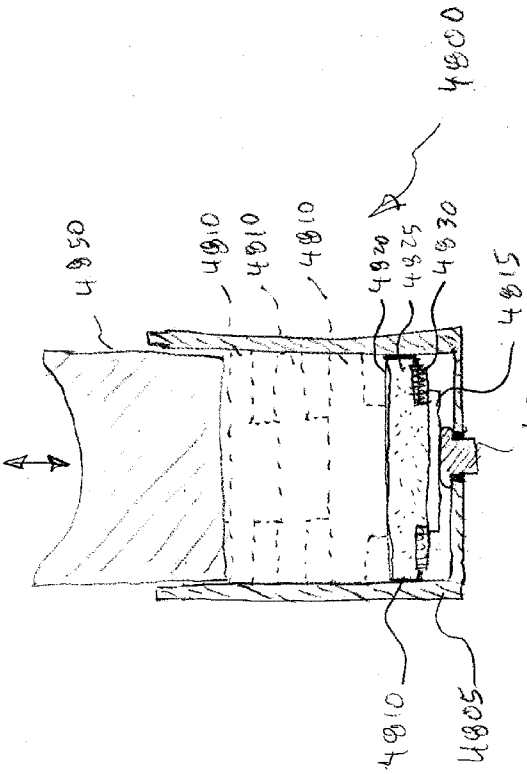


FIG 48-M

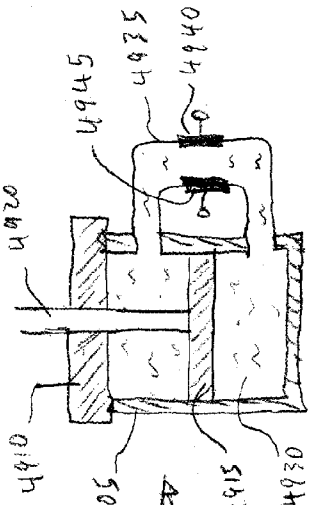


FIG 49-M

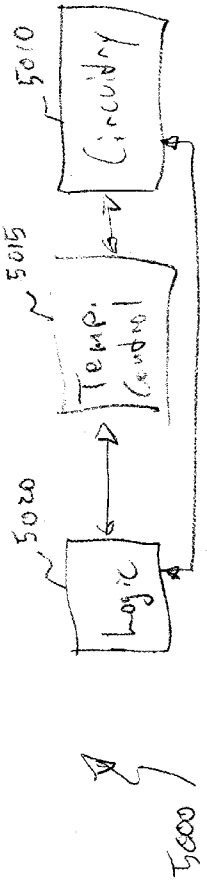


FIG 50-M

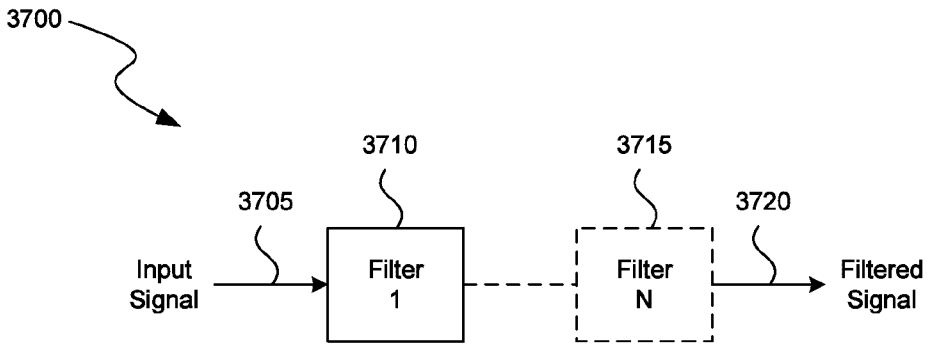


FIG. 37A-N

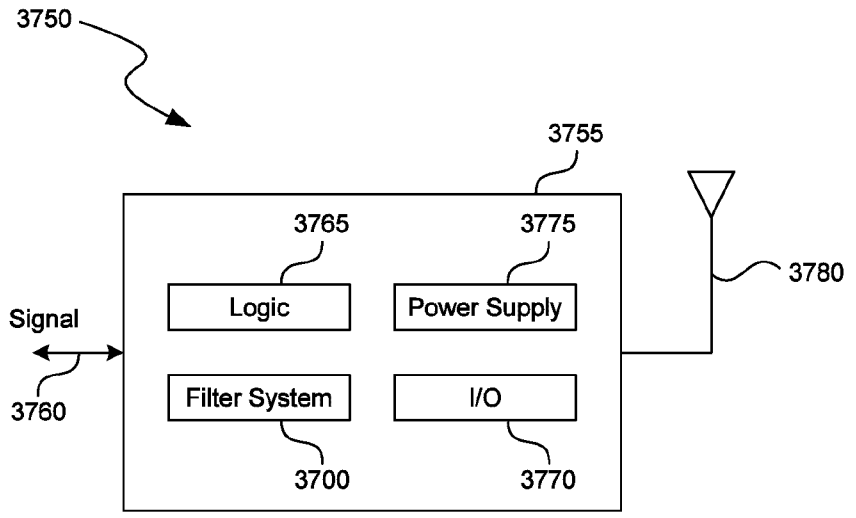


FIG. 37B-N

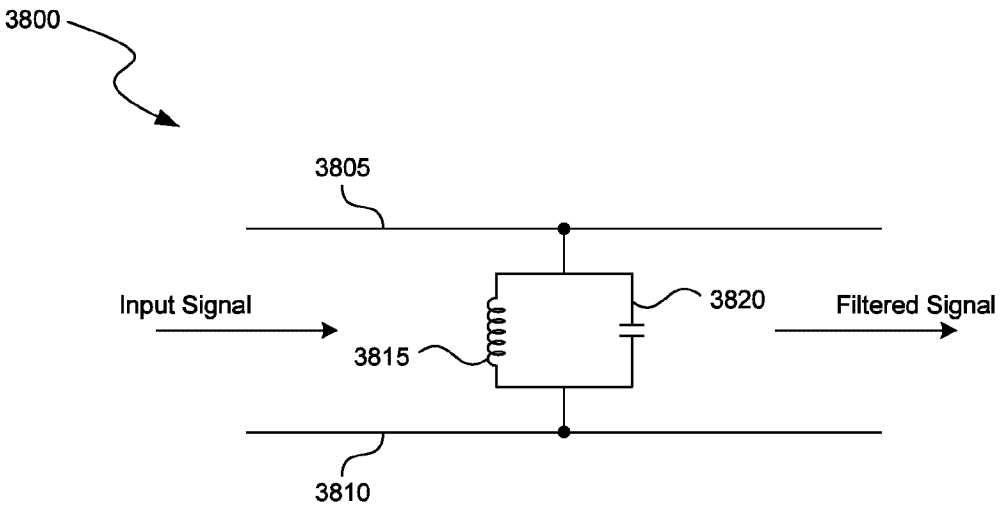


FIG. 38A-N

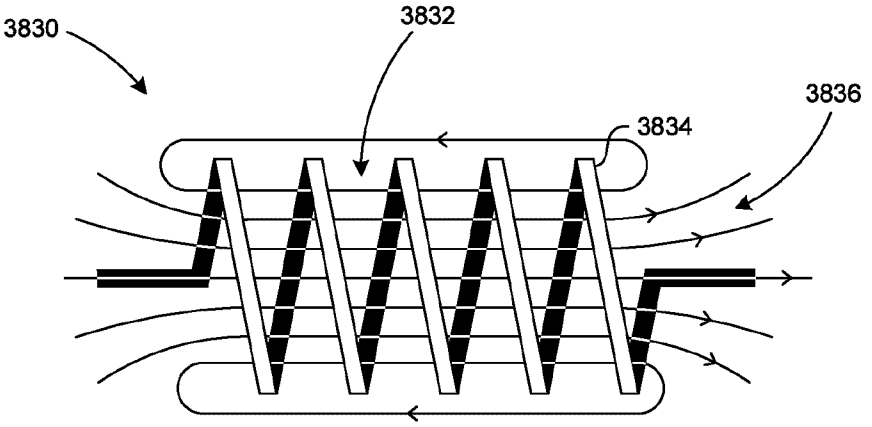


FIG. 38B-N

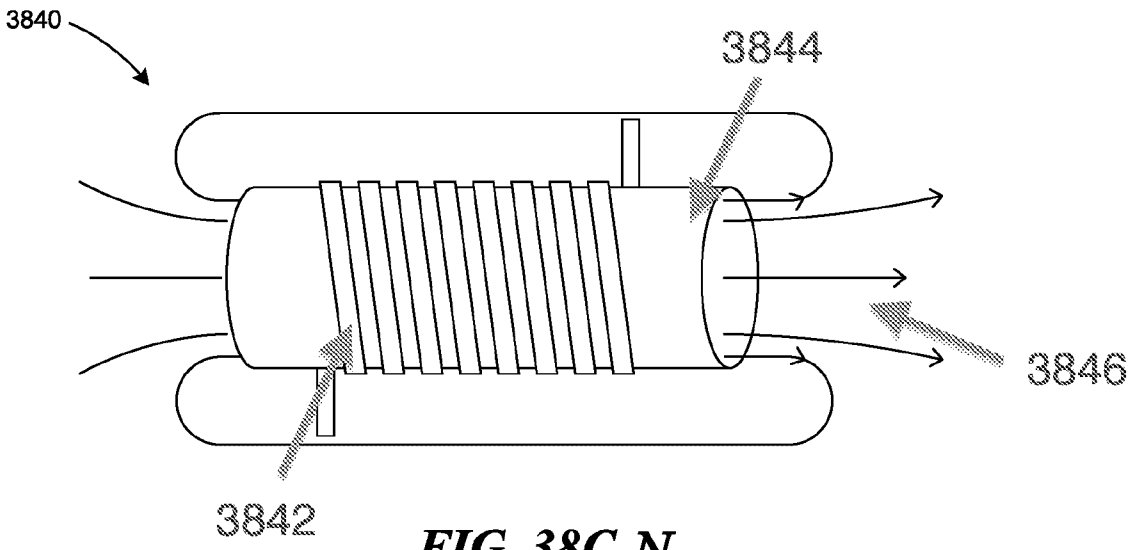


FIG. 38C-N

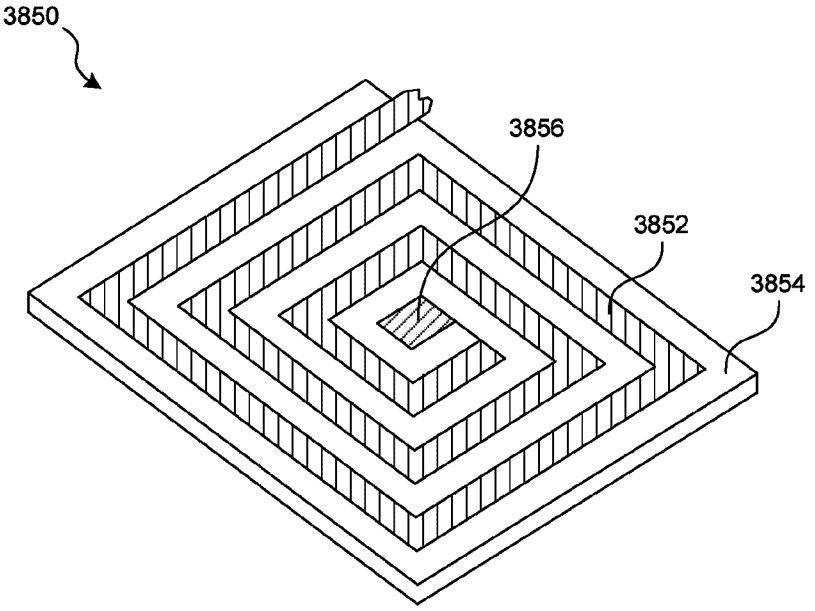


FIG. 38D-N

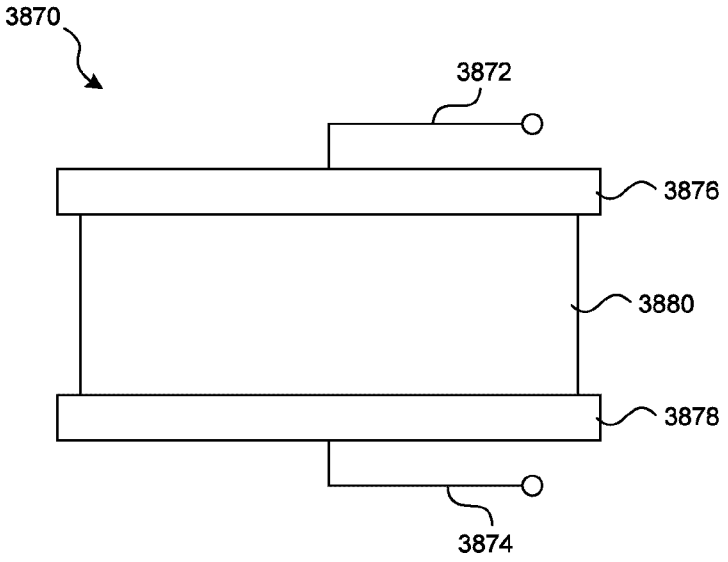


FIG. 38E-N

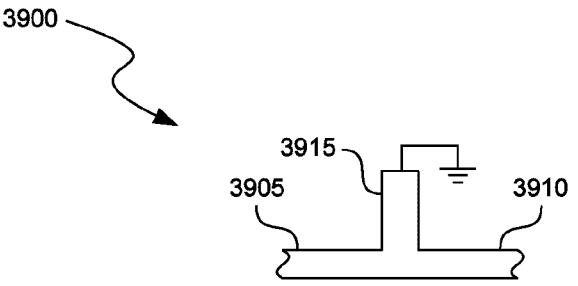


FIG. 39-N

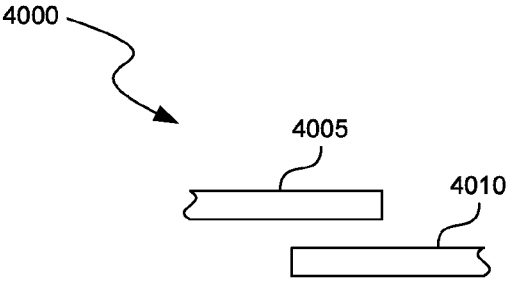


FIG. 40A-N

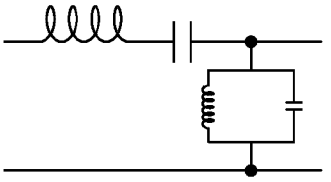


FIG. 40B-N

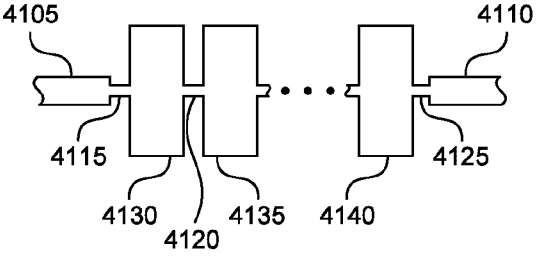


FIG. 41A-N

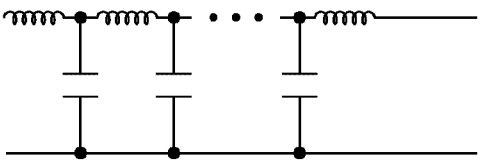


FIG. 41B-N

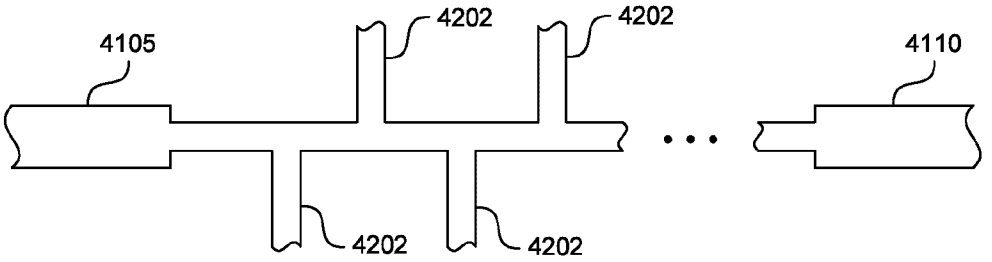


FIG. 42A-N

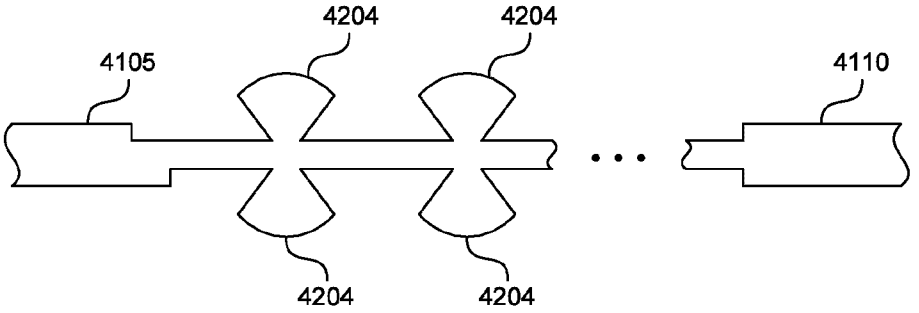


FIG. 42B-N

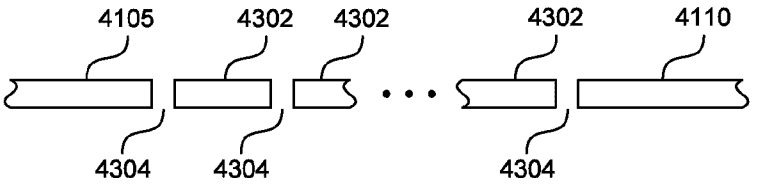


FIG. 43A-N

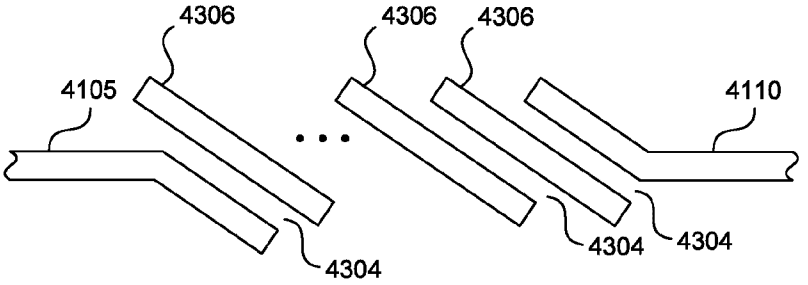


FIG. 43B-N

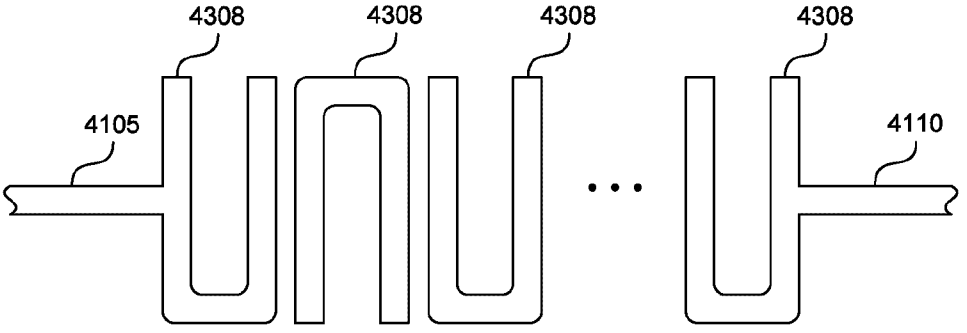


FIG. 43C-N

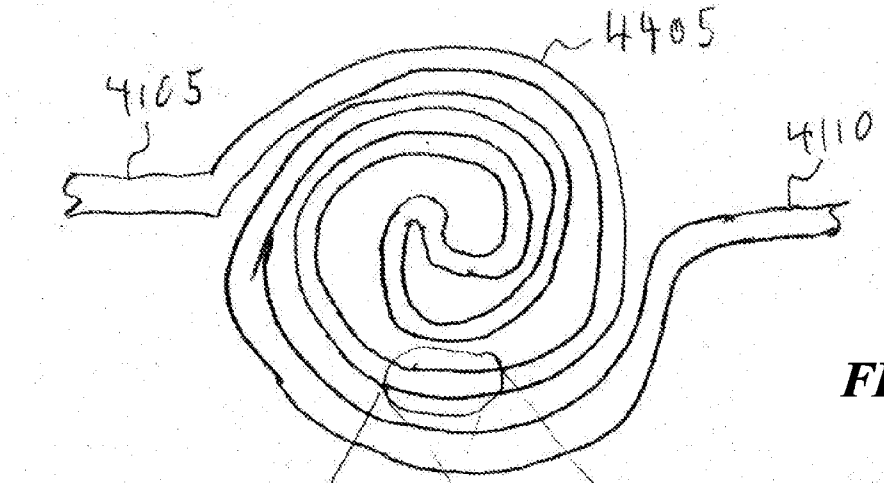


FIG. 44A-N

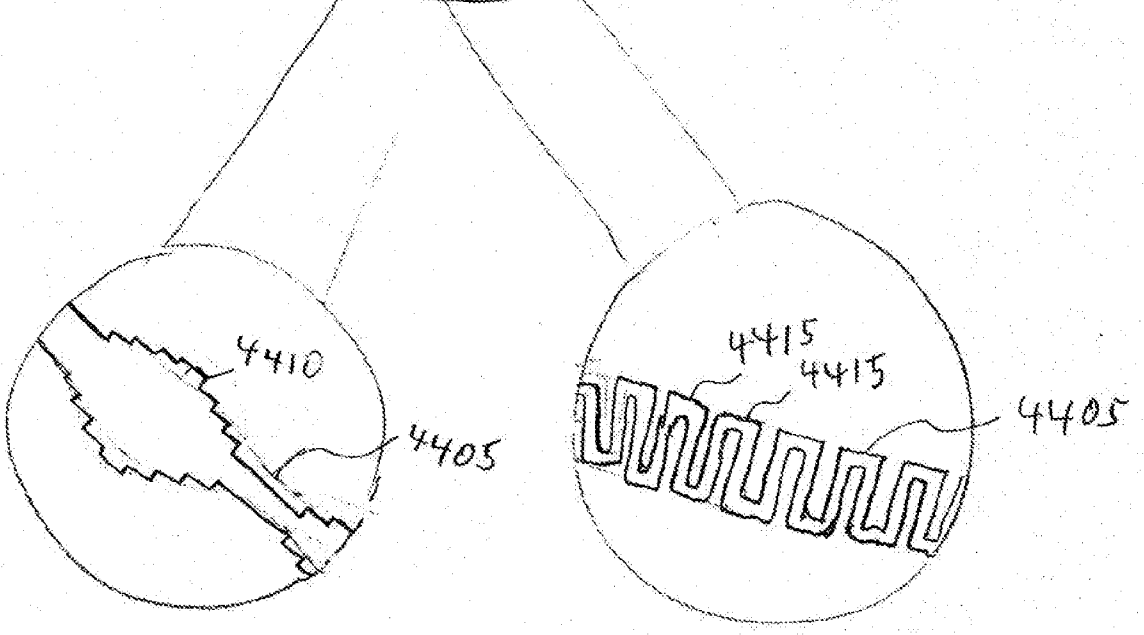


FIG. 44B-N

FIG. 44C-N

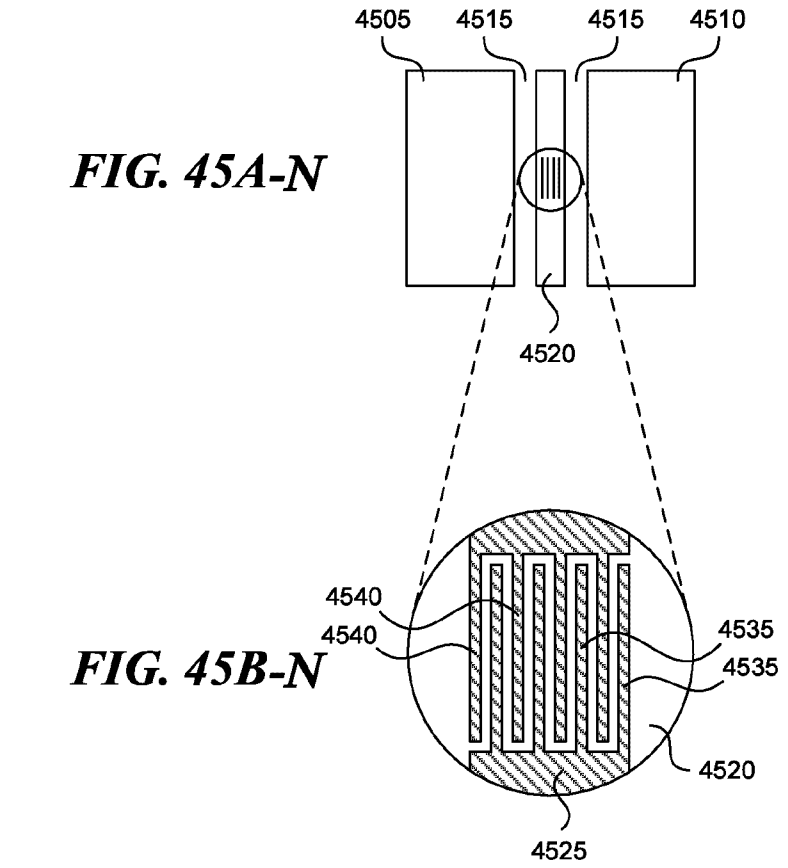


FIG. 45A-N

FIG. 45B-N

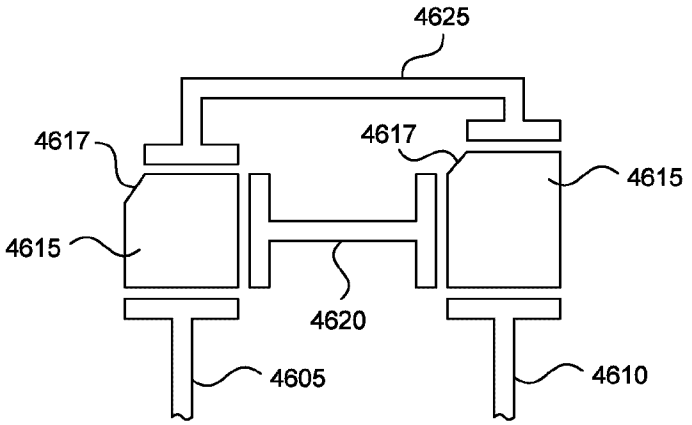


FIG. 46-N

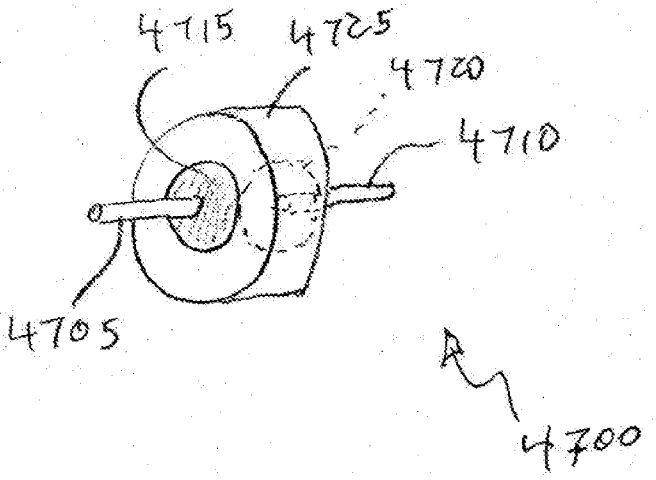


FIG. 47-N

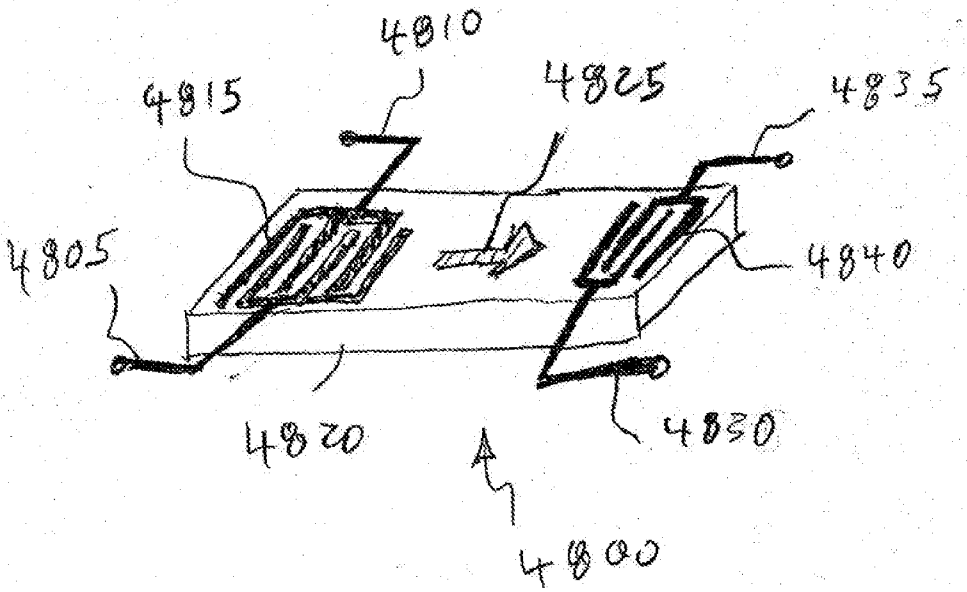


FIG. 48-N

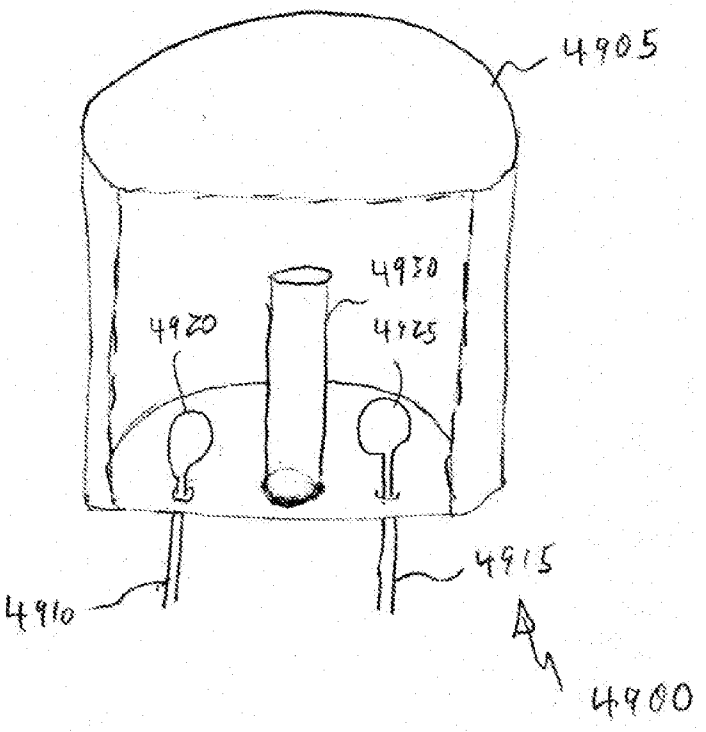


FIG. 49-N

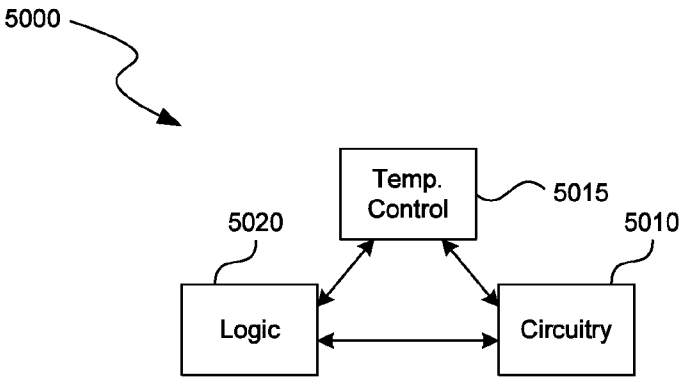


FIG. 50-N

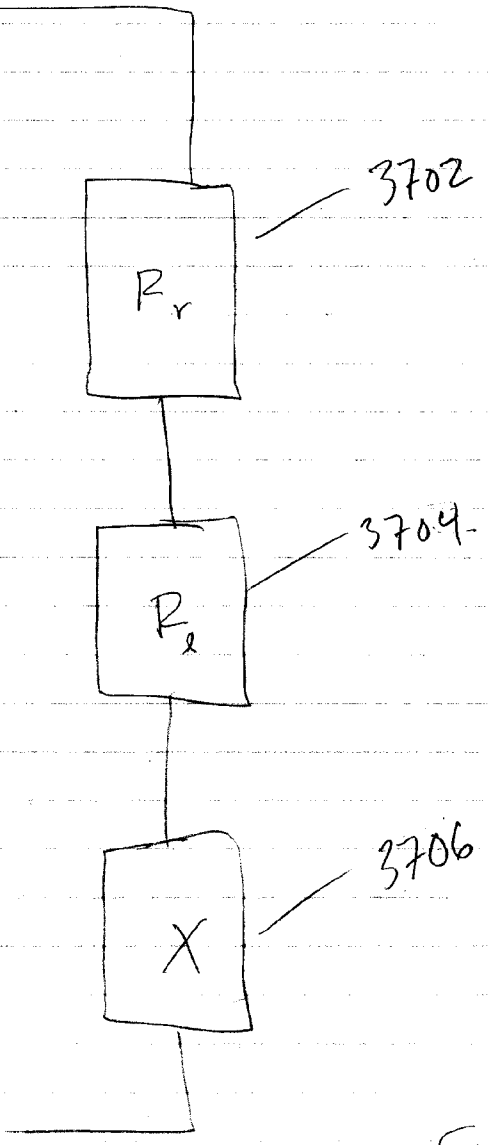


FIG 37-O

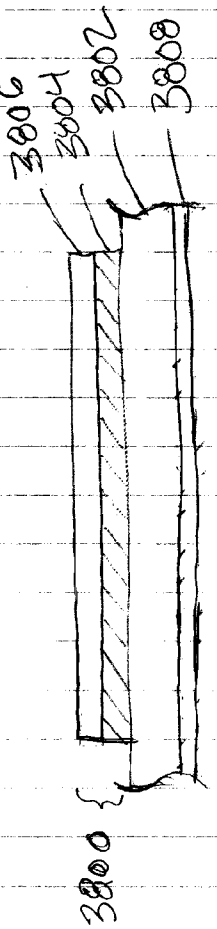


FIG 38-O

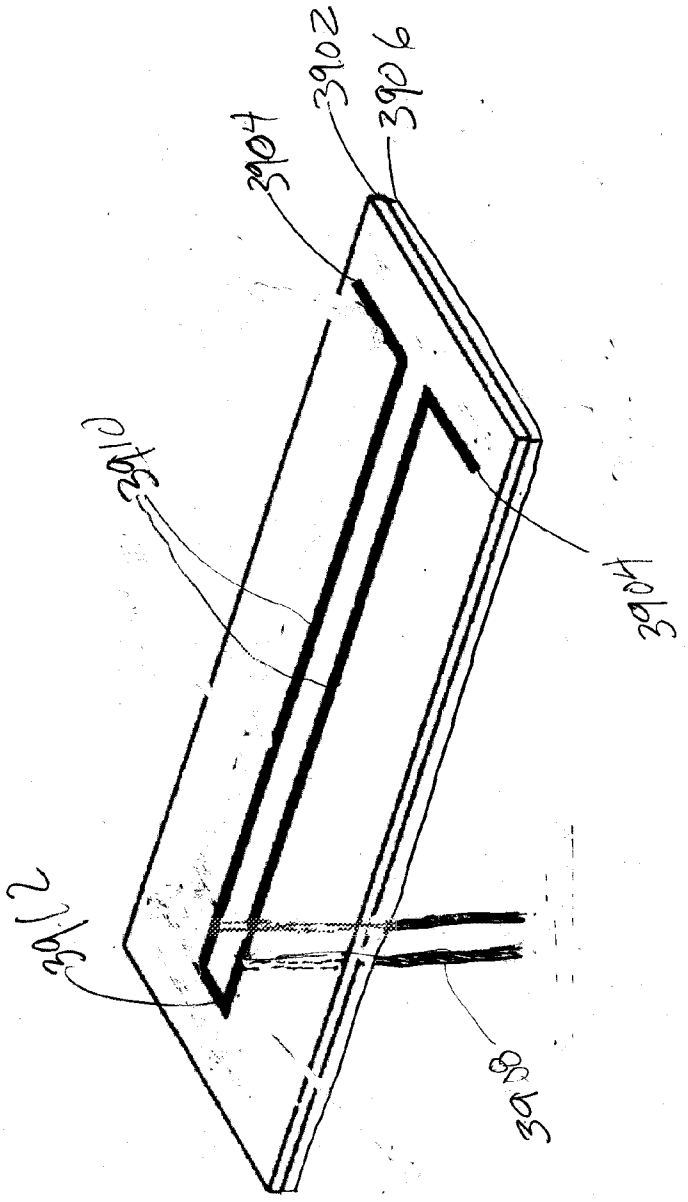


FIG. 39-O

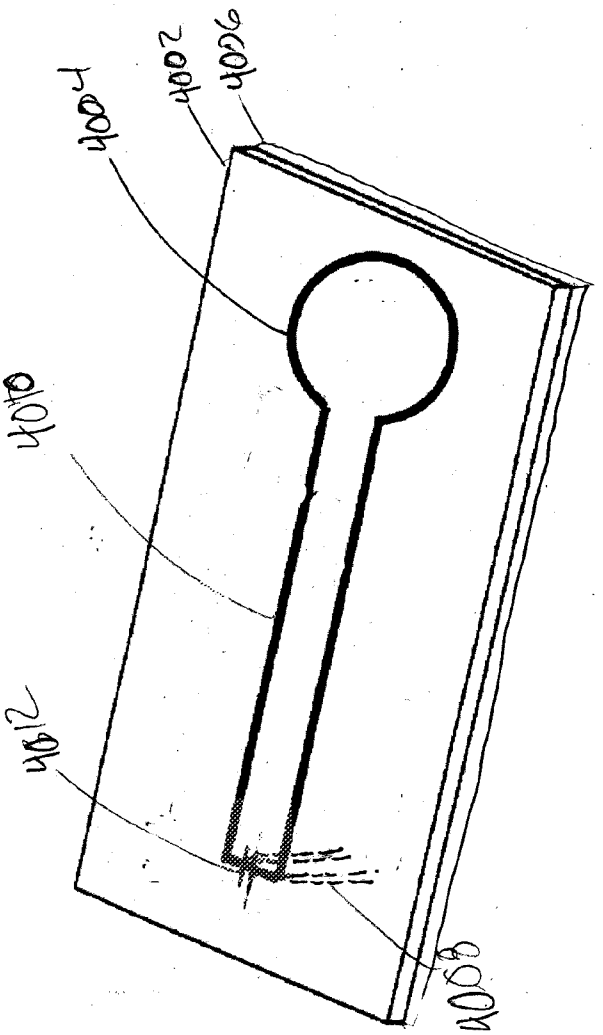


FIG. 40-O

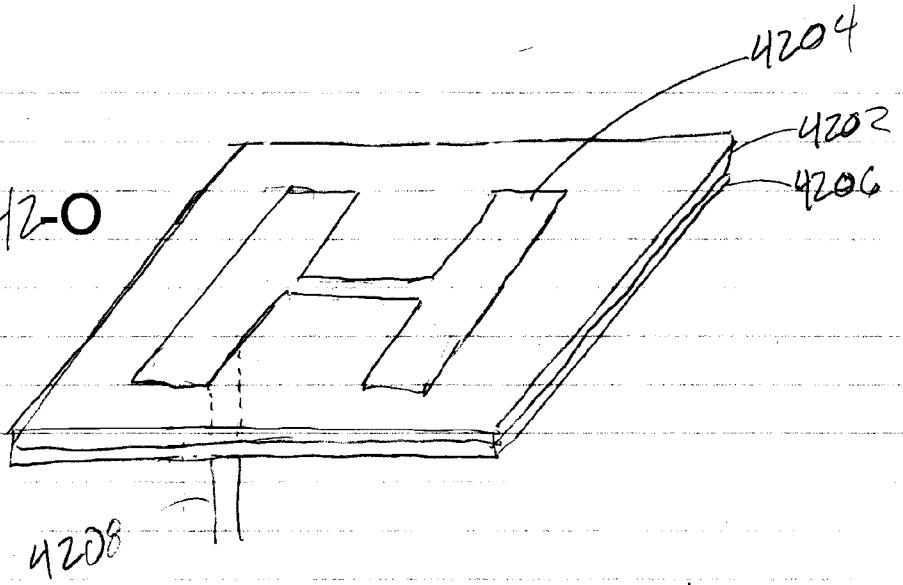


Fig 42-O

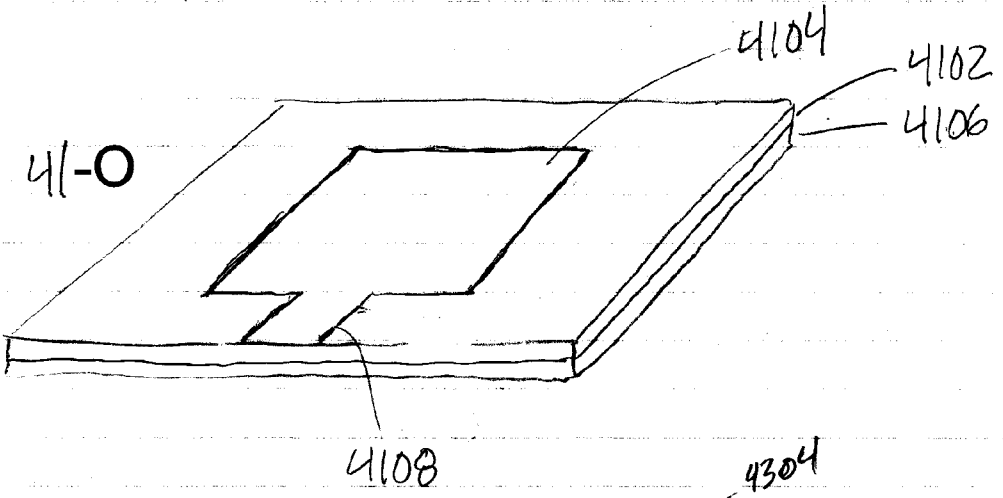


Fig. 41-O

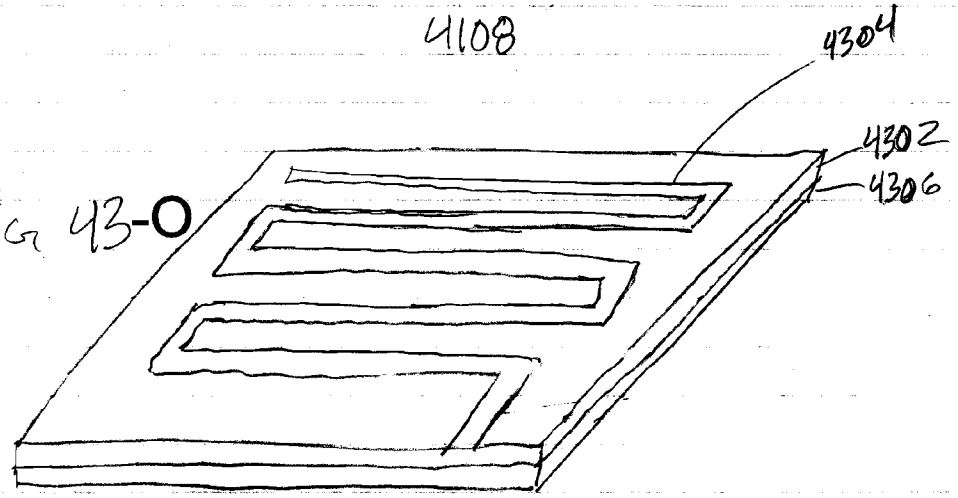


Fig 43-O

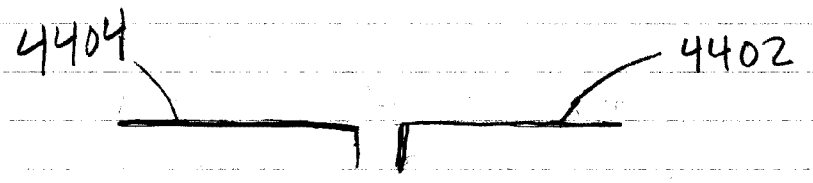


FIG. 44-0

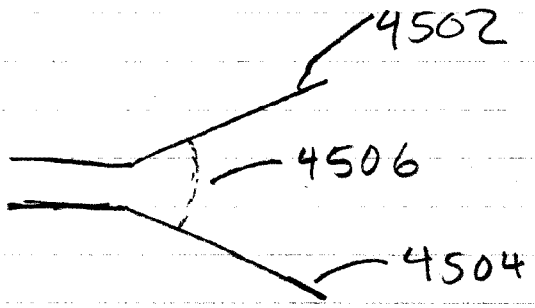


FIG. 45-0

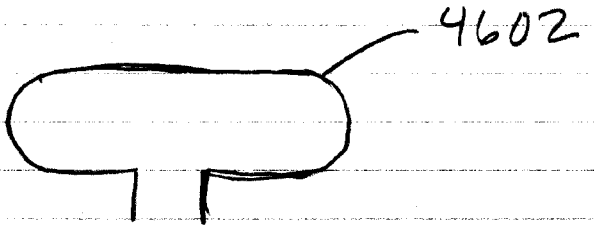


FIG 46-0

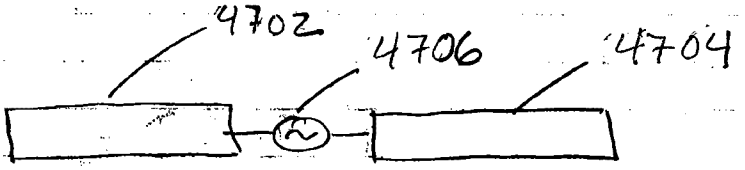


Fig. 47 A-O

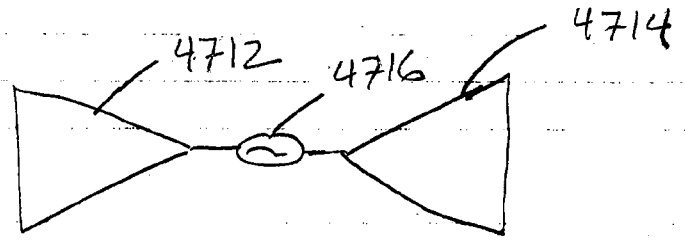


Fig. 47 B-O

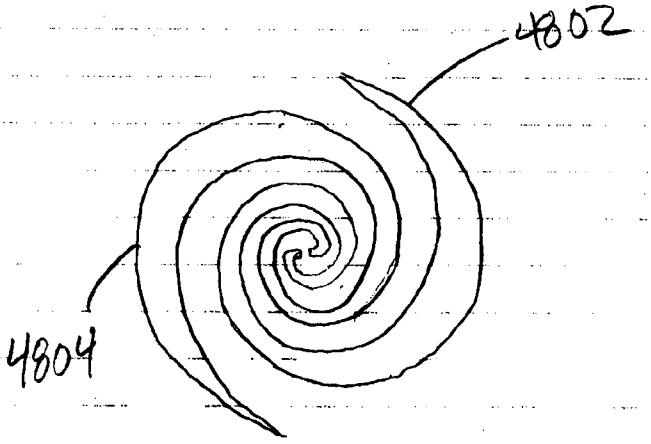


Fig. 48-O

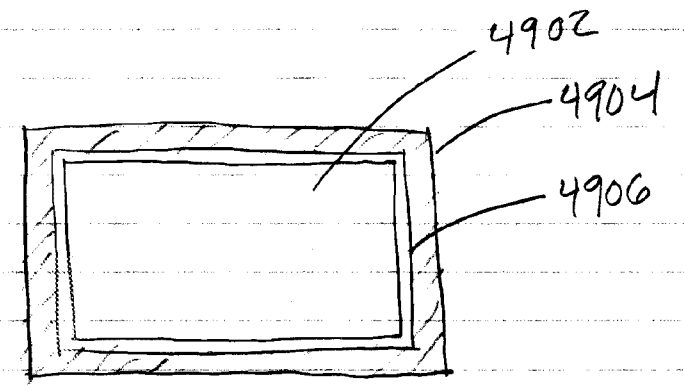


FIG. 49-O

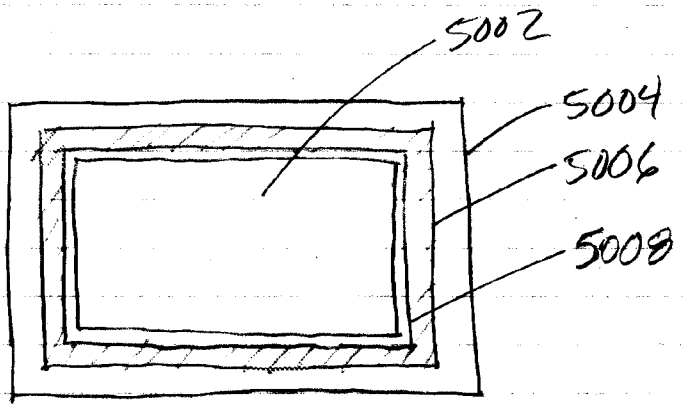


FIG 50-O

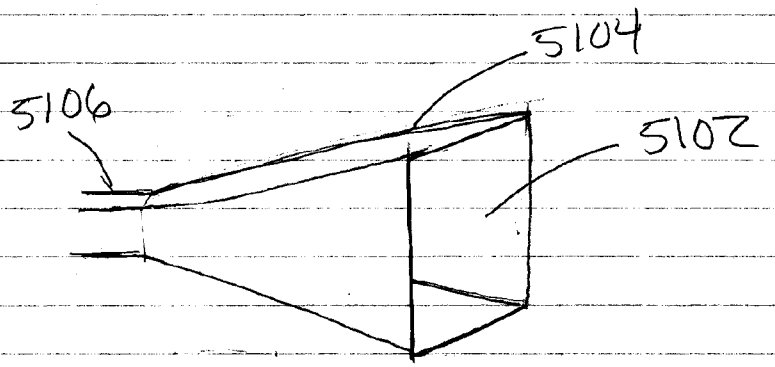


FIG 51-0

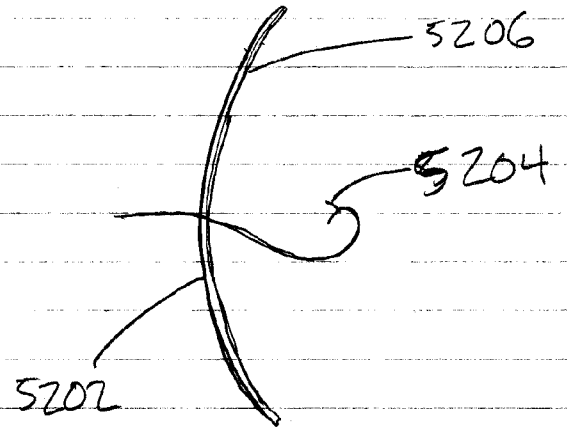


FIG 52-0

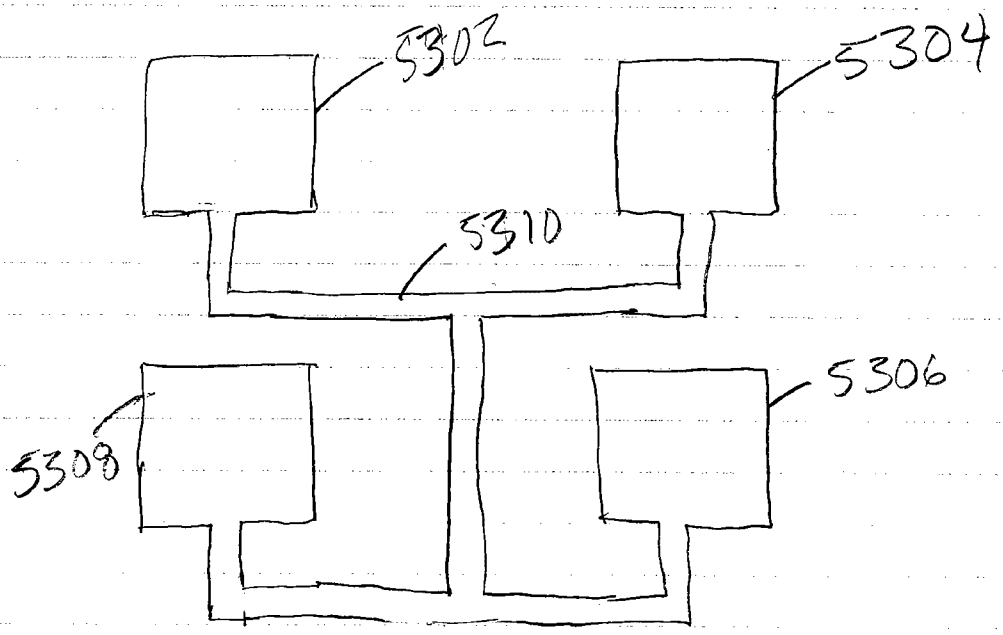


FIG 53 A-O

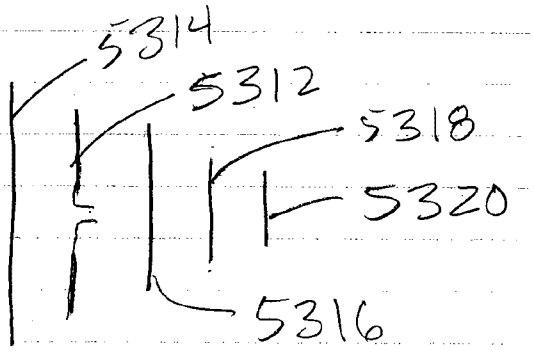


FIG 53 B-O

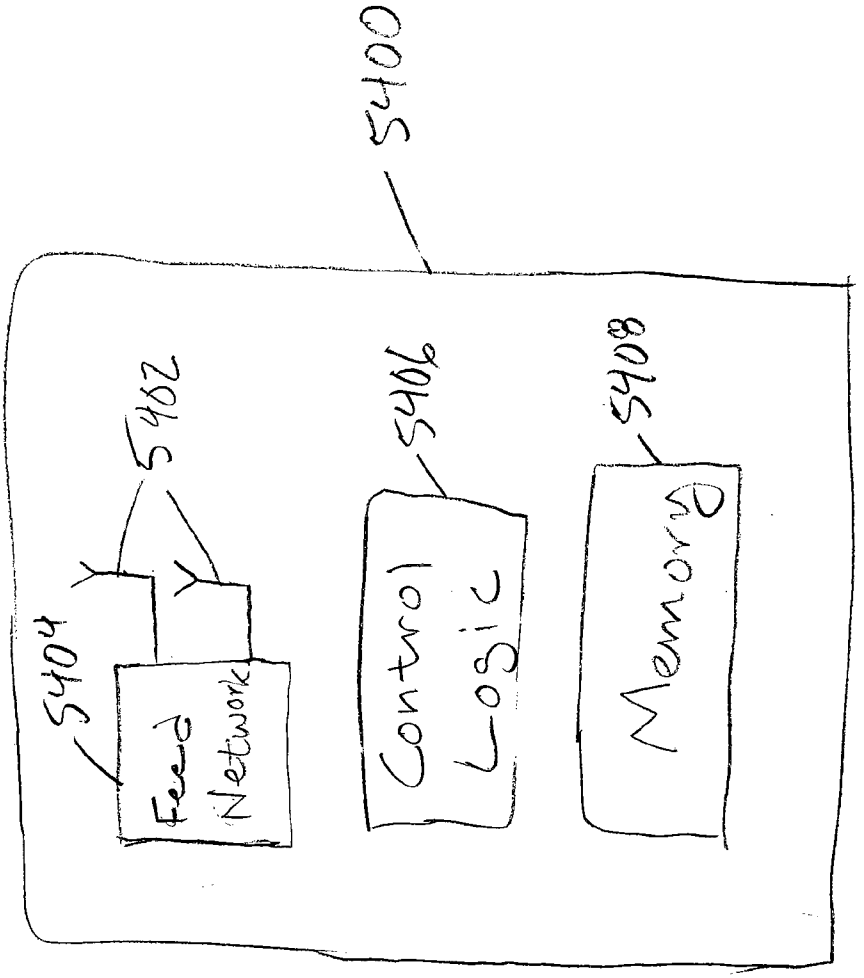


FIG 54-O

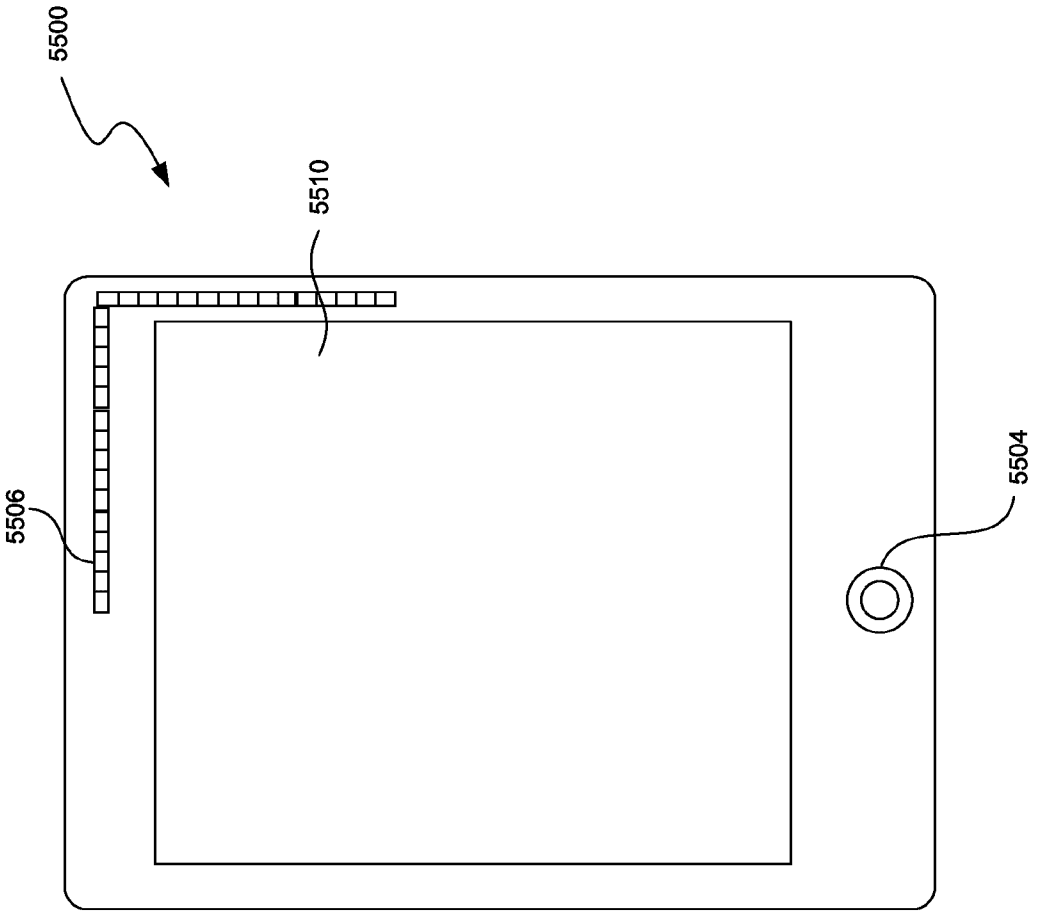


FIG. 55-O

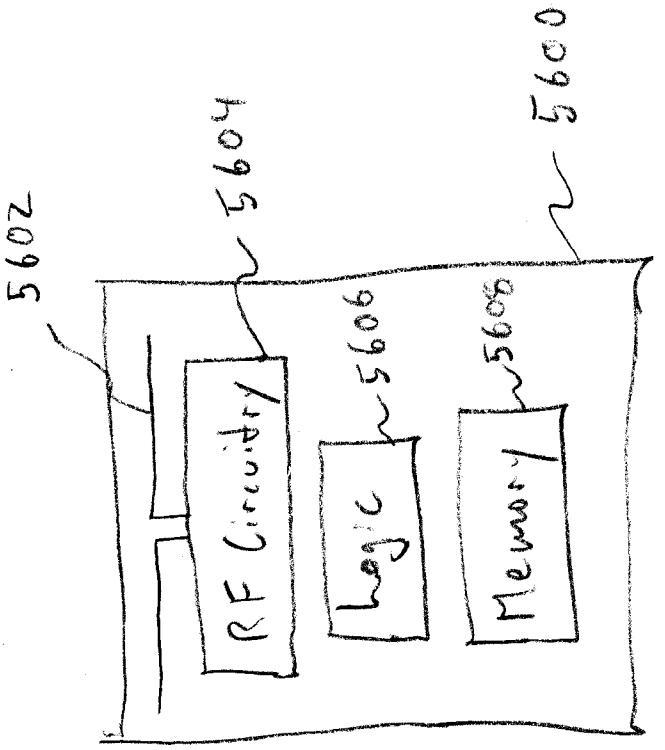


FIG 56-O

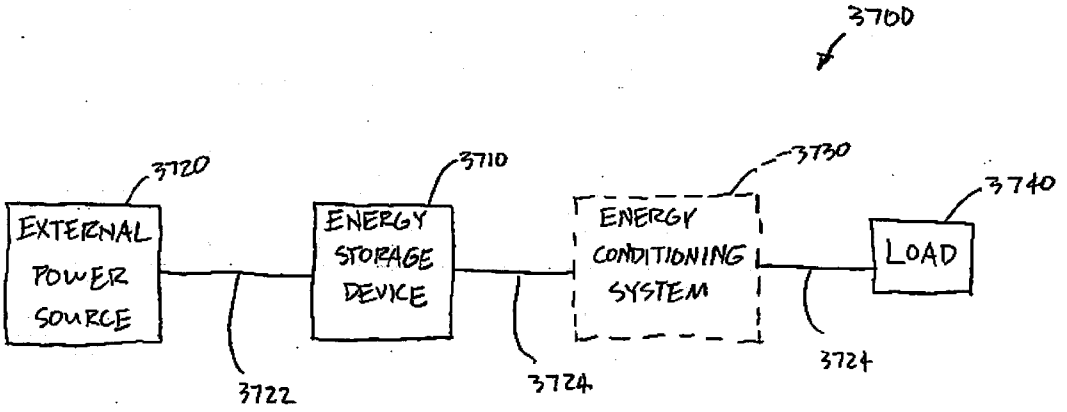

3700
3720
EXTERNAL POWER SOURCE
3710
ENERGY STORAGE DEVICE
3730
ENERGY CONDITIONING SYSTEM
3740
LOAD
3722
3724
3724

Fig. 37-P

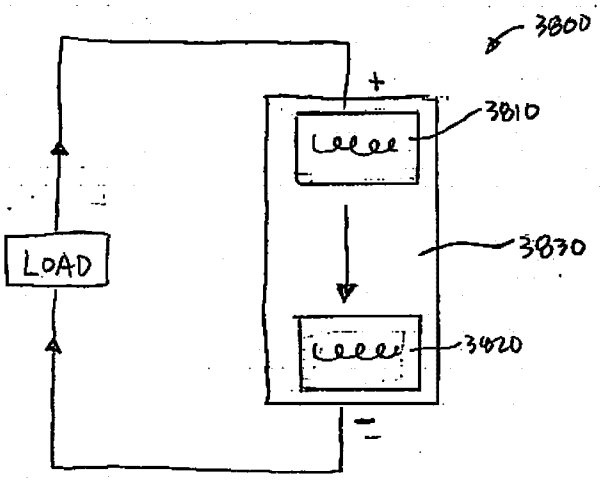


Fig. 38-P

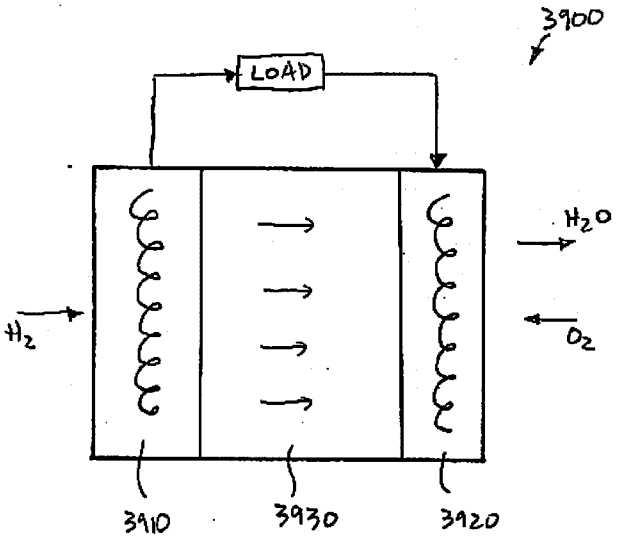


Fig. 39-P

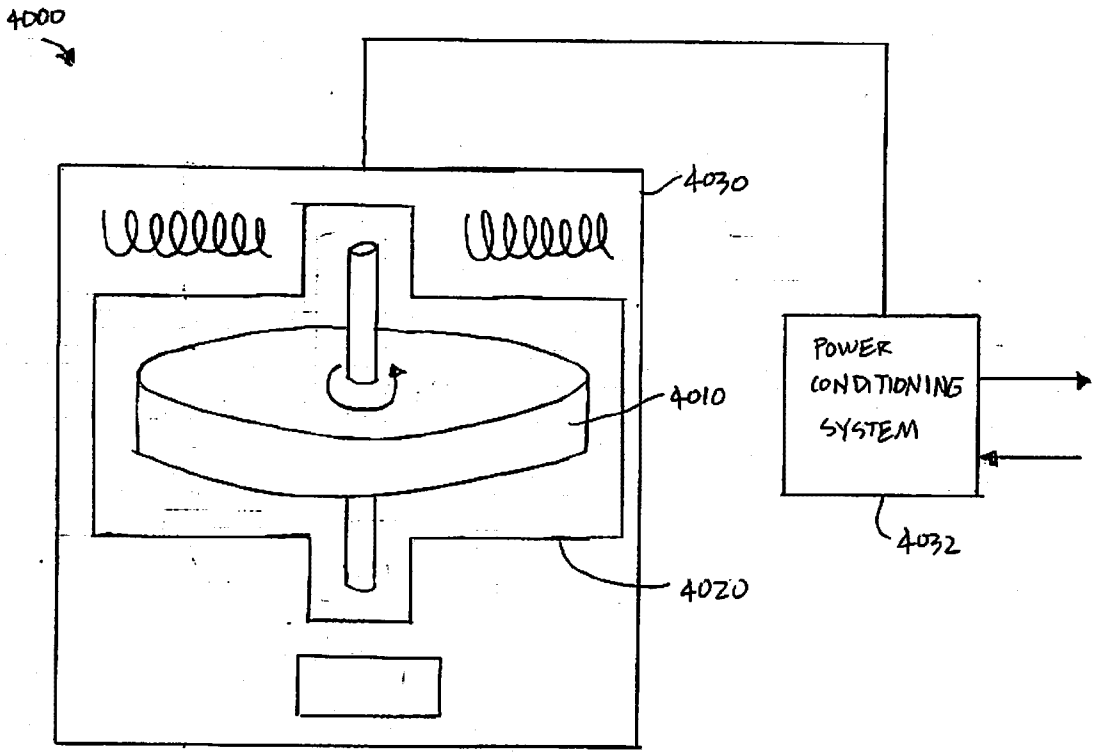


Fig. 40-P

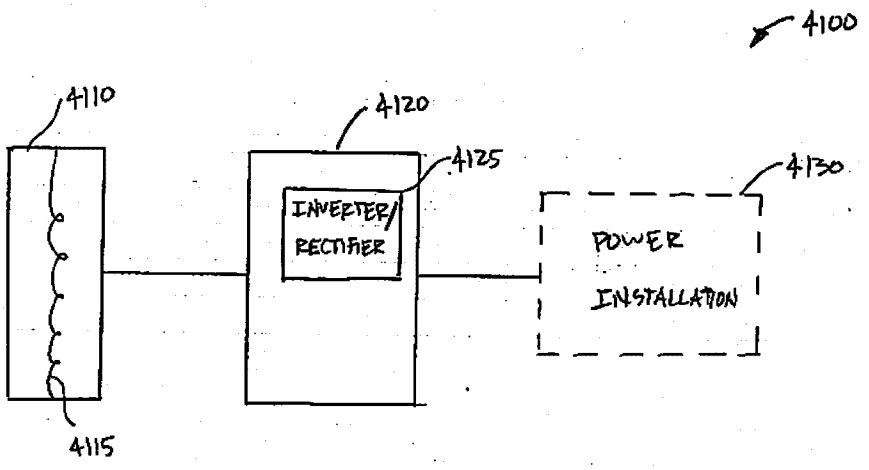

4100
4110
4120
4125
4130
INVERTER/
RECTIFIER
POWER
INSTALLATION
4115

Fig. 41A-P

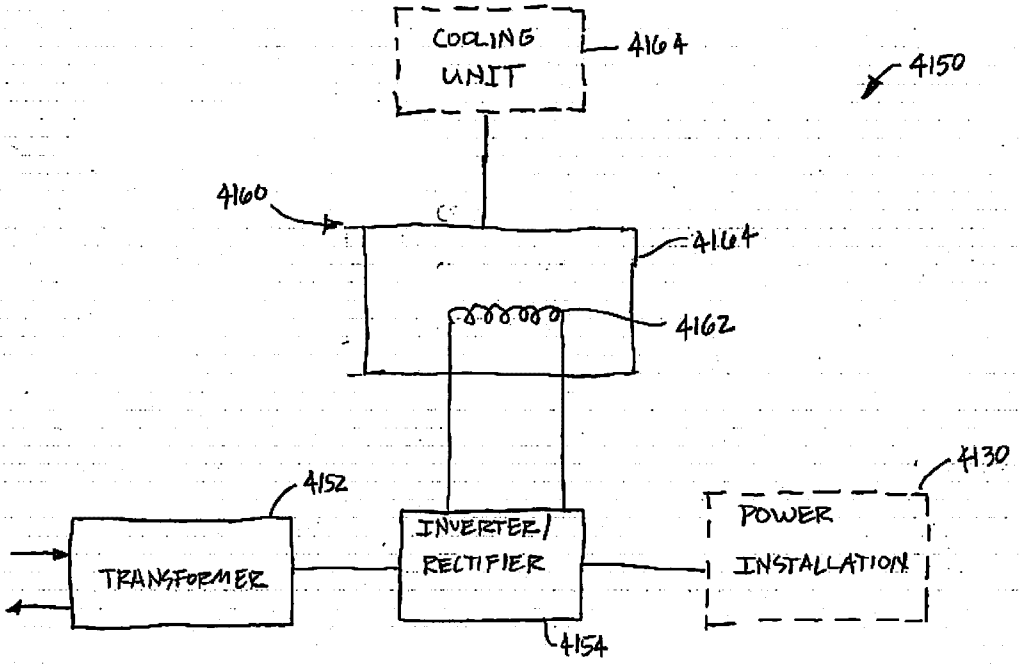

COOLING UNIT
4164
4150
4160
4164
4162
4130
4152
TRANSFORMER
INVERTER/ RECTIFIER
POWER INSTALLATION
4154

Fig. 41B-P

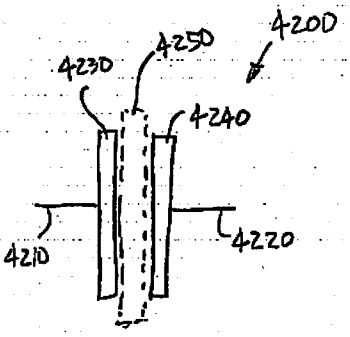


Fig. 42-P

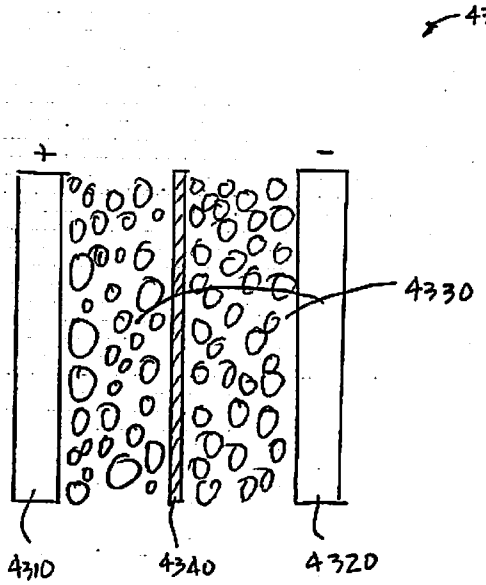


Fig. 43-P

FIG 37-Q

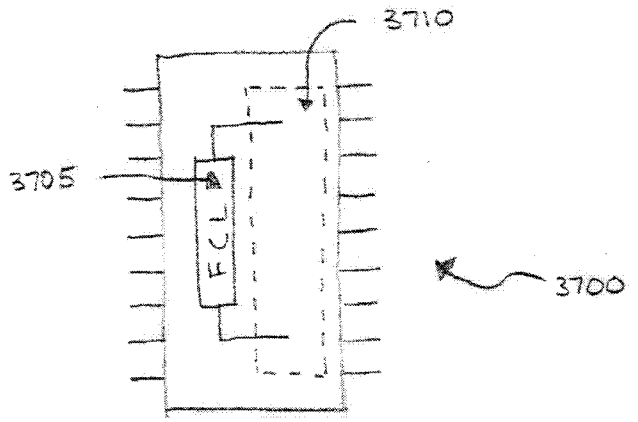


FIG 38-Q

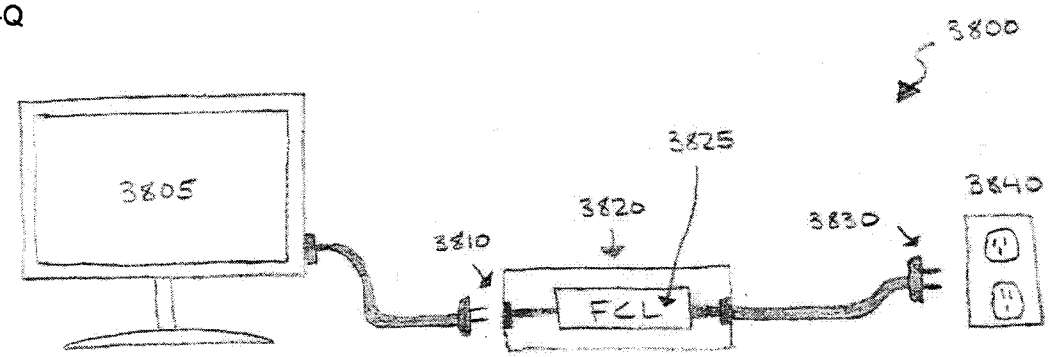


FIG 40A-Q

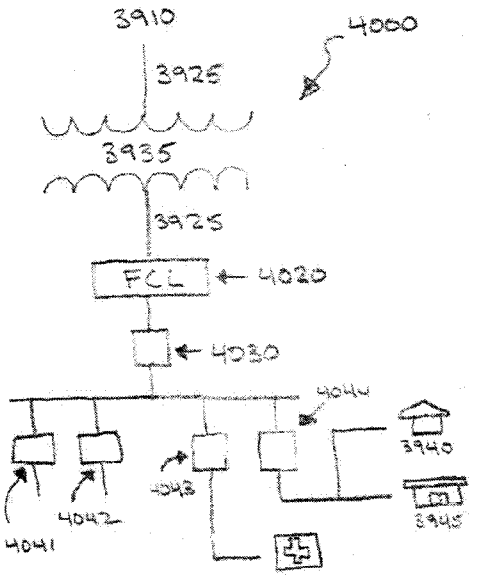


FIG 40B

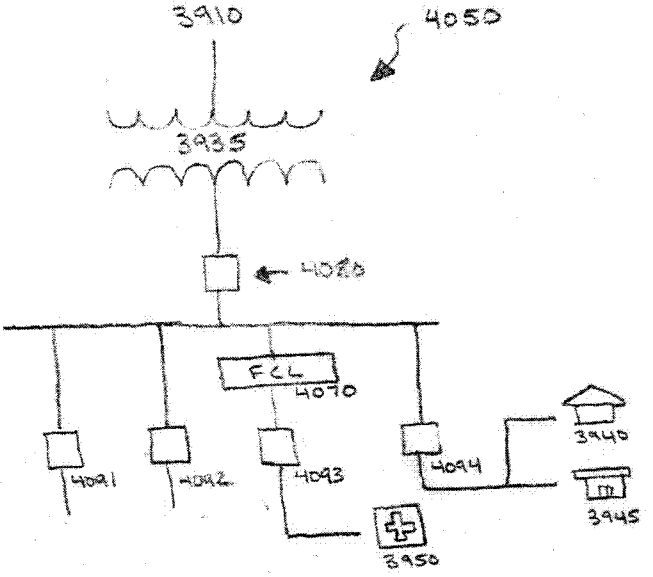


FIG 39-Q

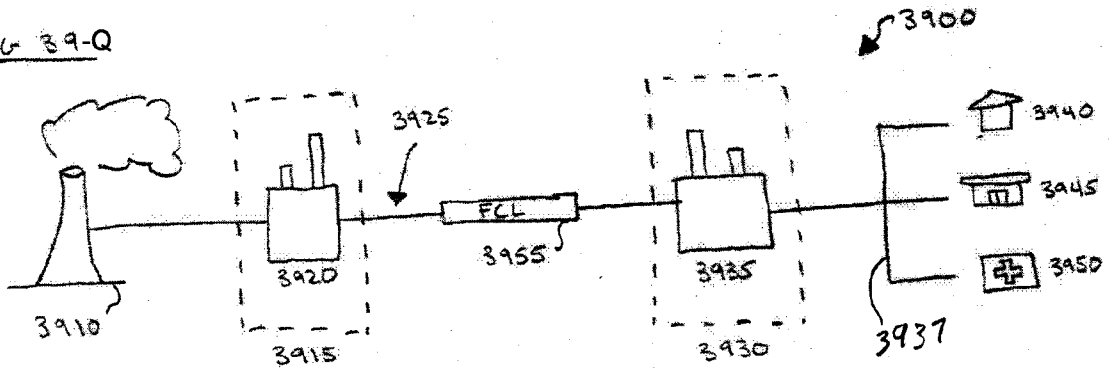


FIG 42-Q

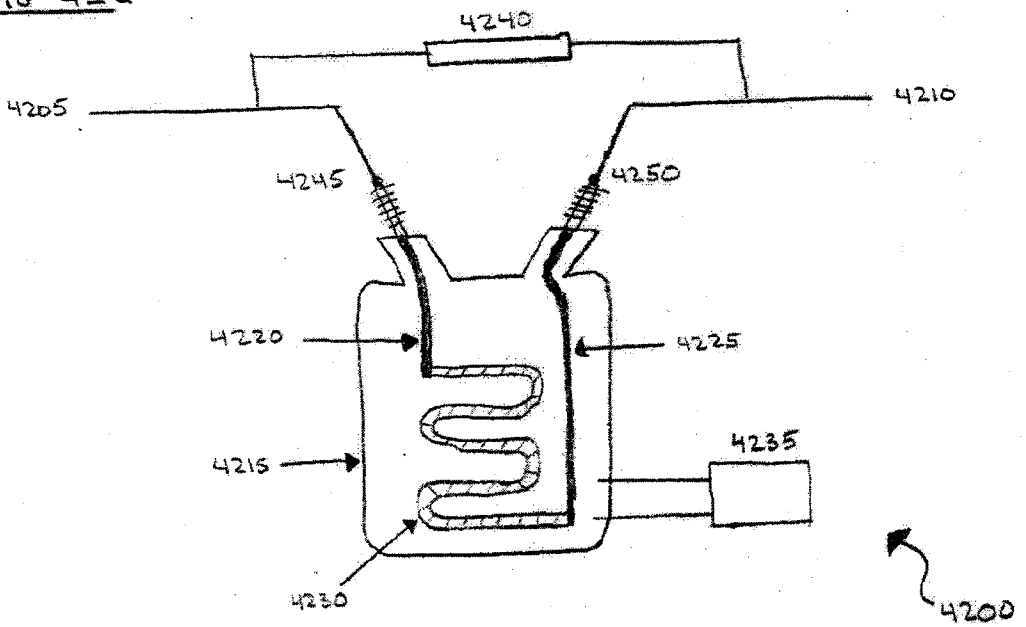


FIG 44-Q

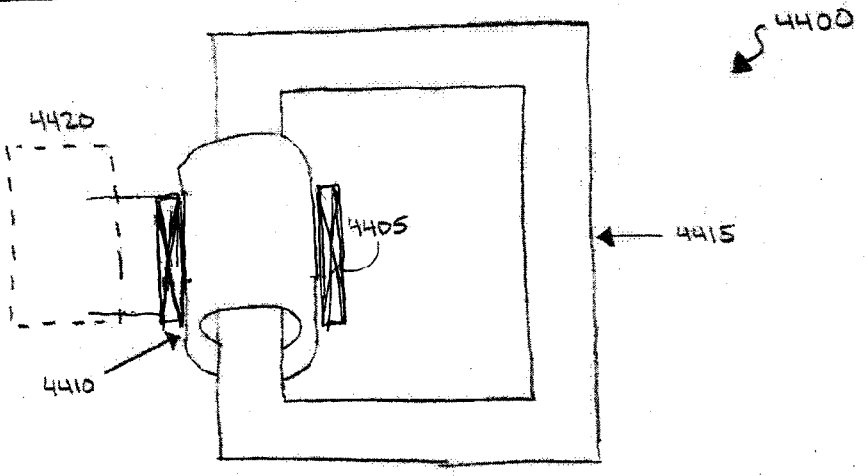


FIG 43-Q

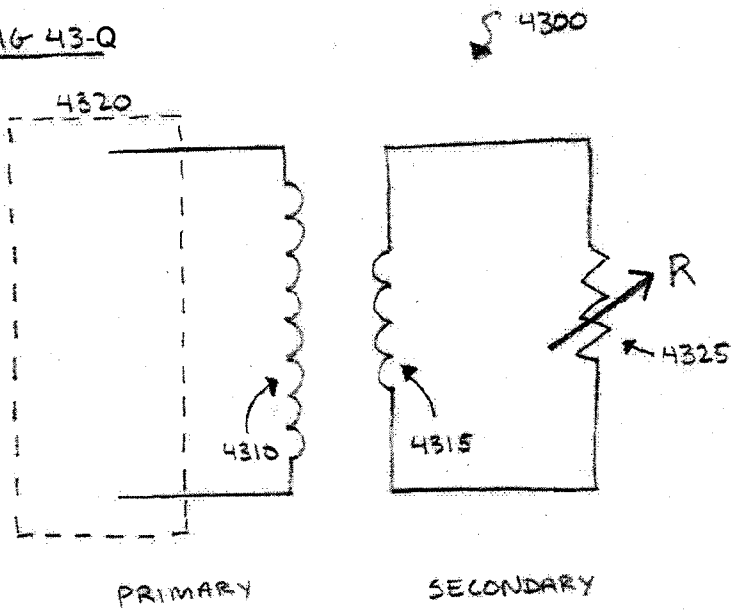
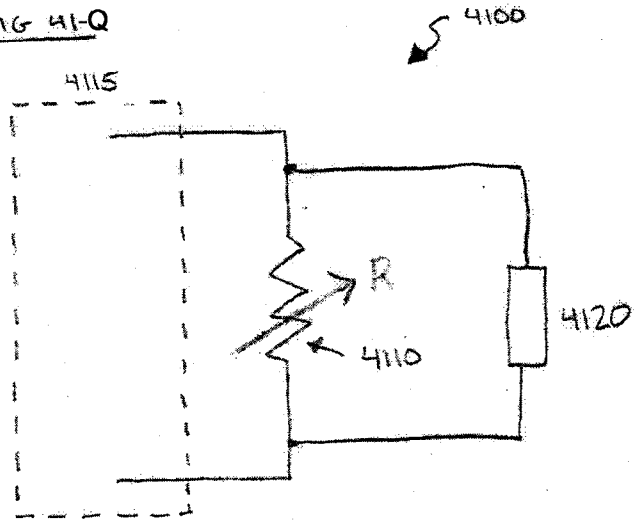


FIG 41-Q



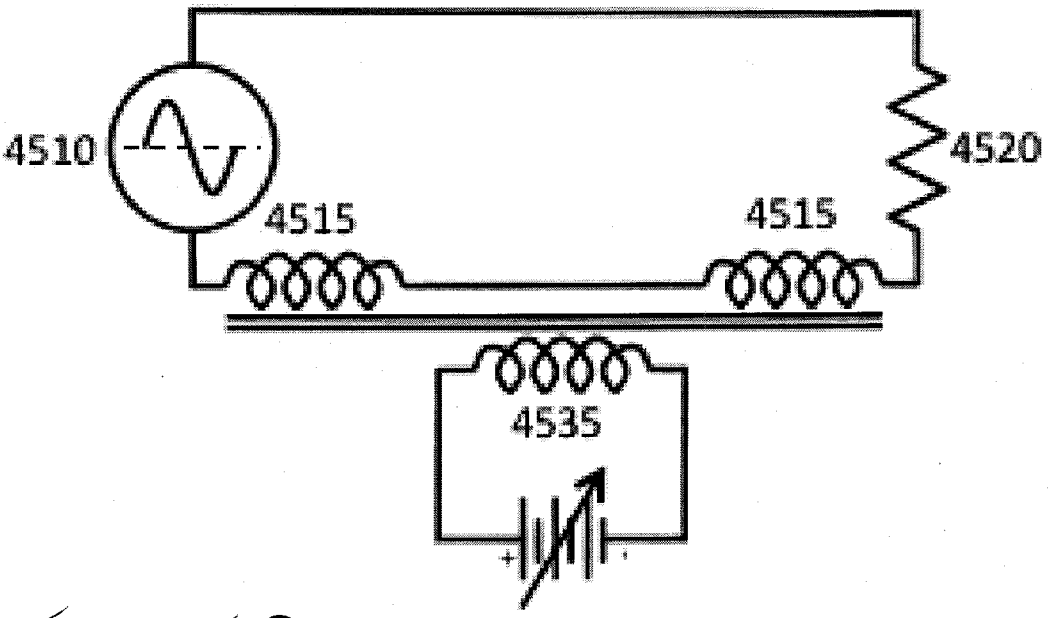


FIG 45-Q

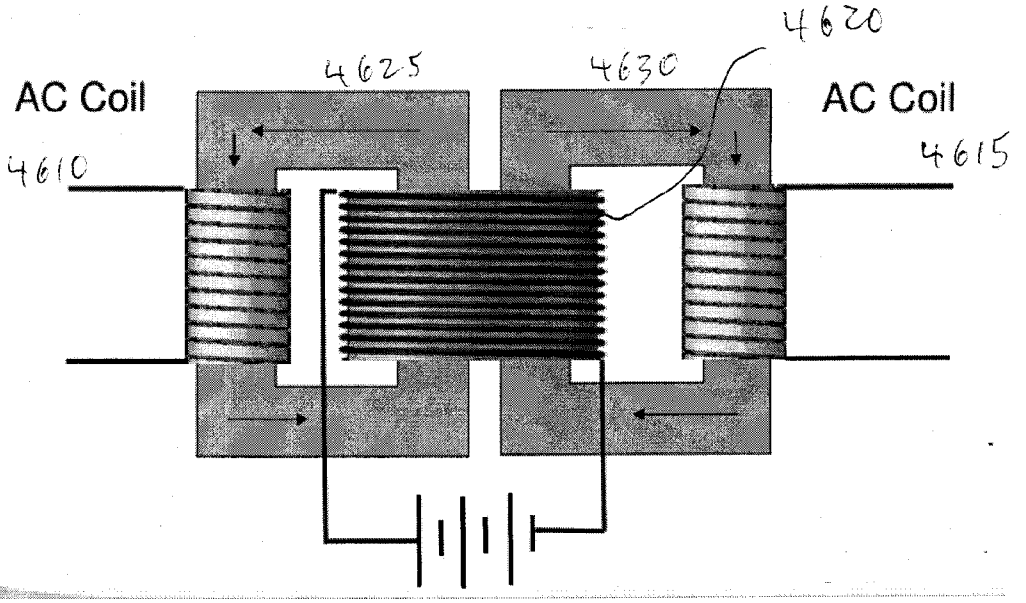


FIG 46-Q

First Inventor:
Title:

Attorney Docket No.: 765078039US

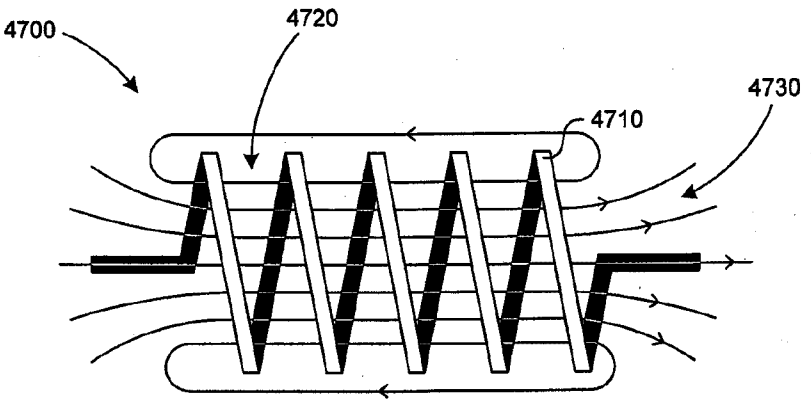


FIG. 47-Q

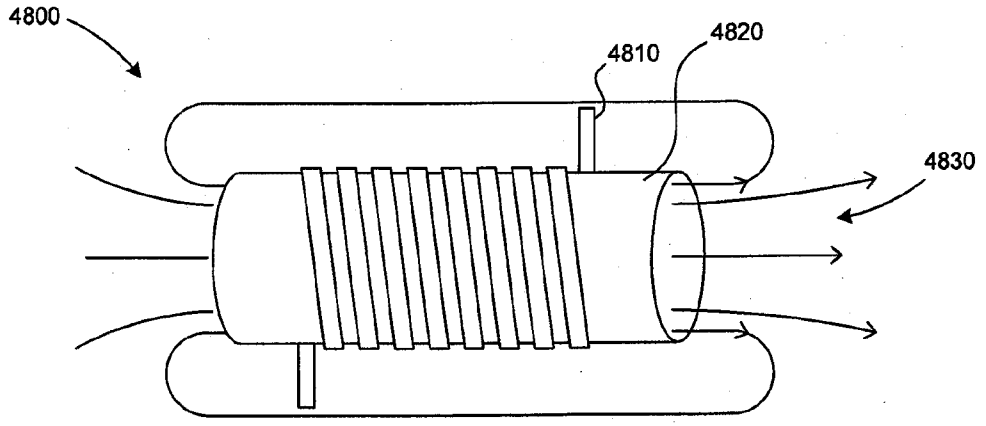


FIG. 48-Q

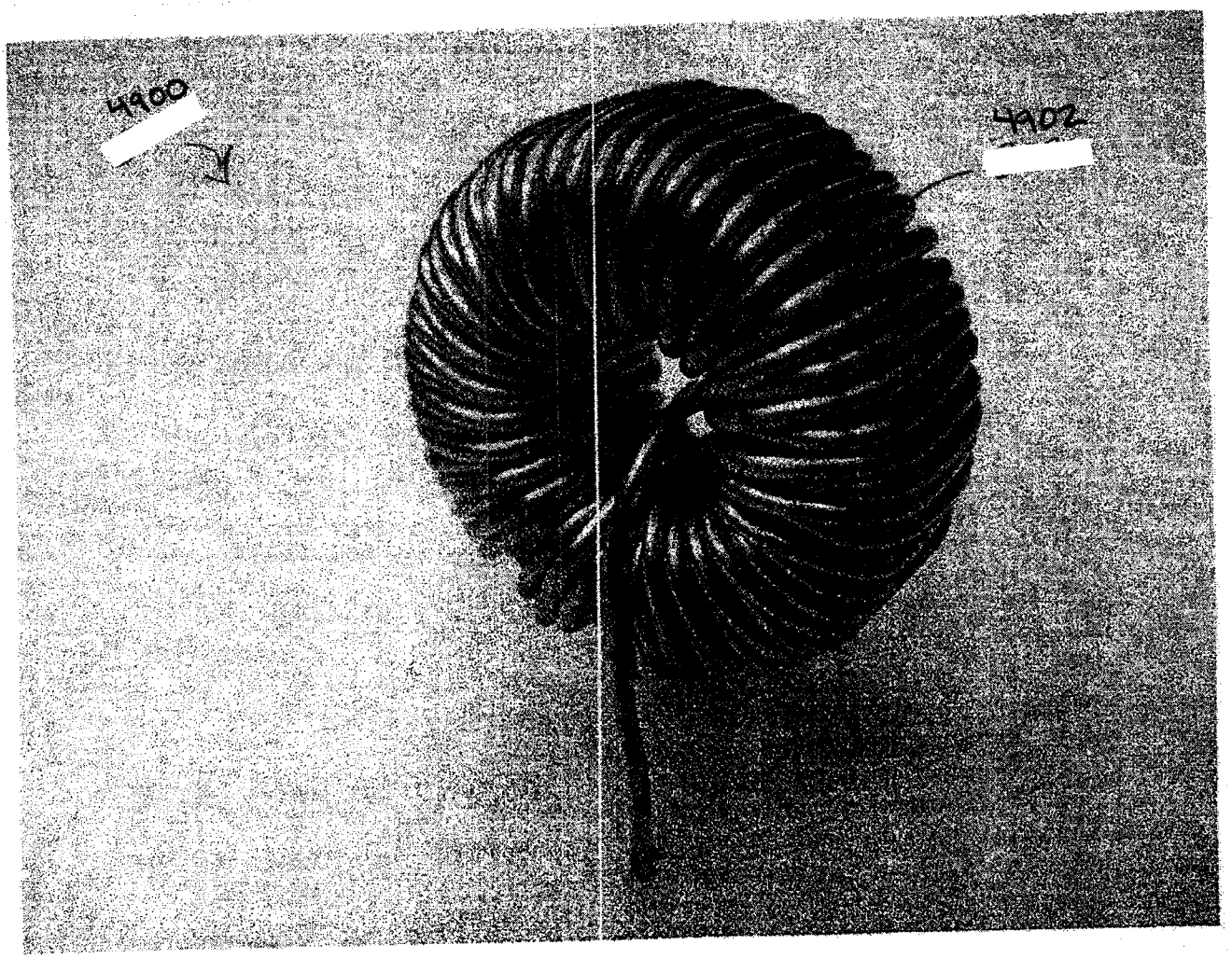


FIG 49A-Q

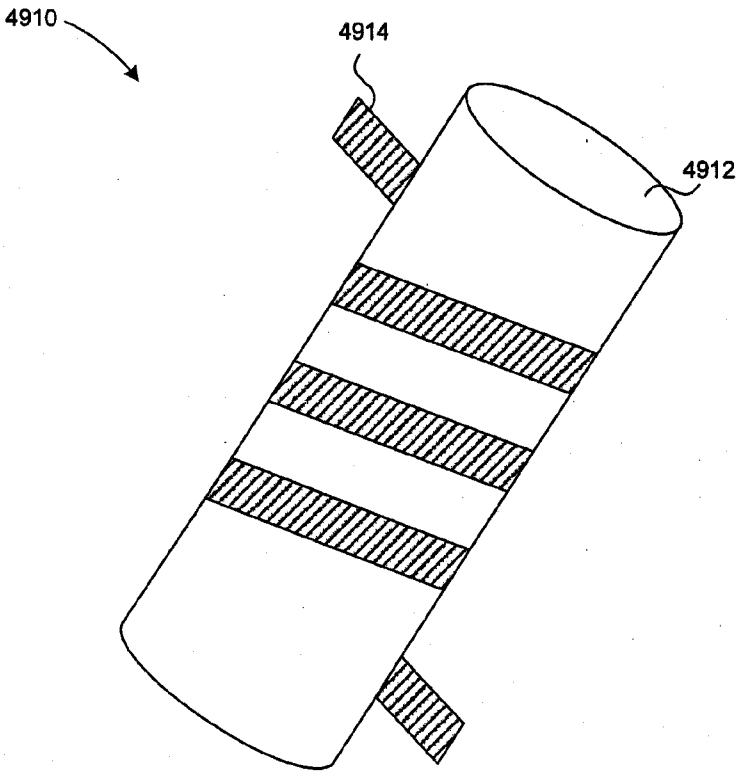


FIG. 49B-Q

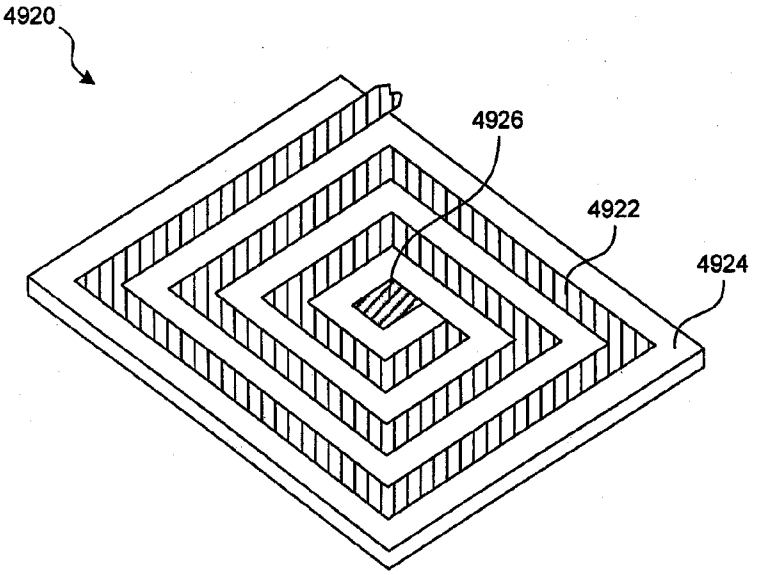


FIG. 49C-Q

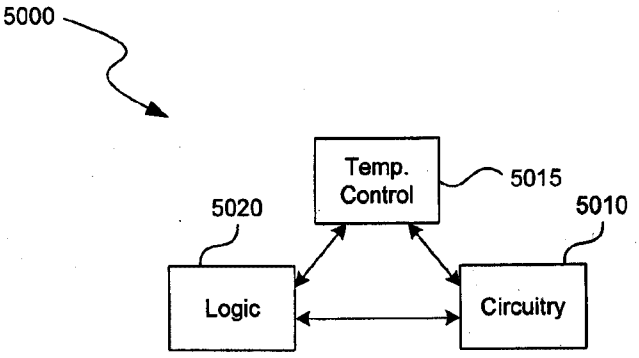


FIG. 50-Q

FIG 37-R

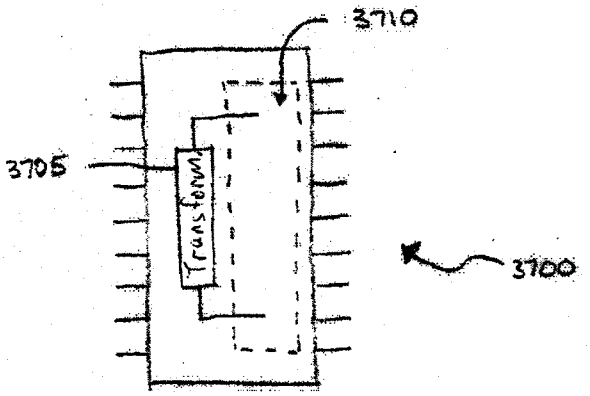


FIG 38-R

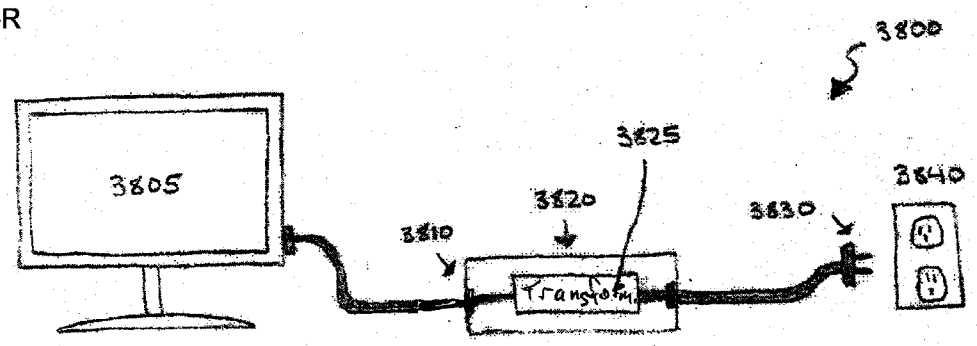


FIG 40-R

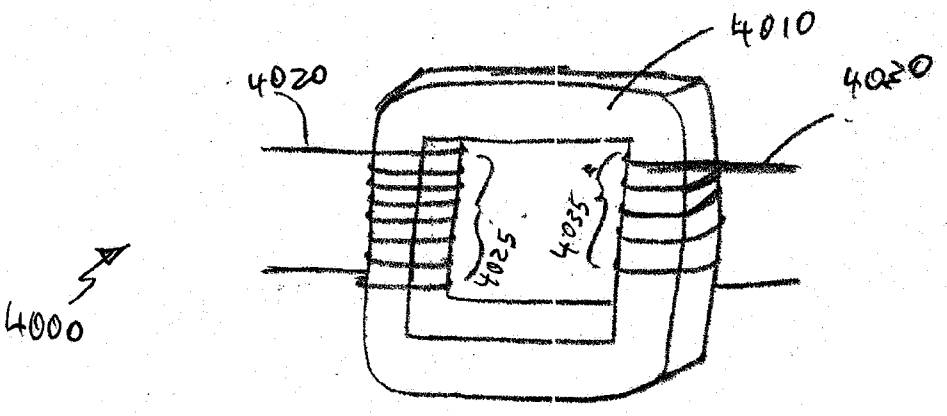


FIG 39-R

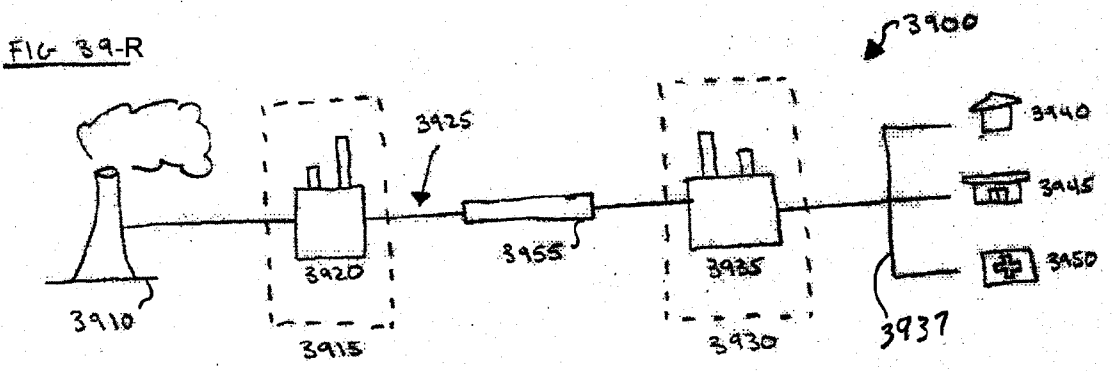
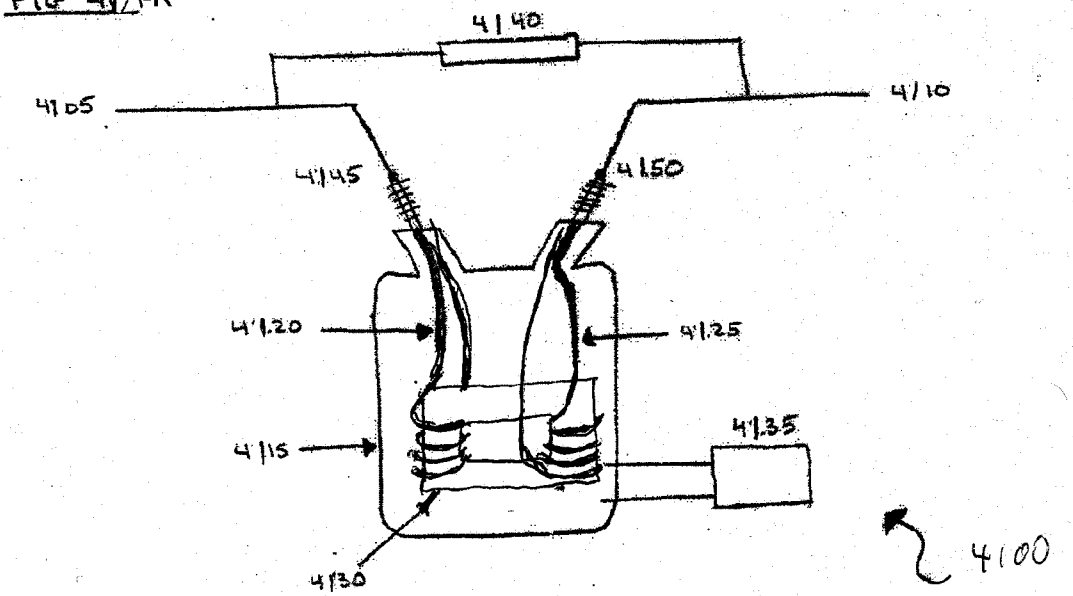


FIG 41A-R



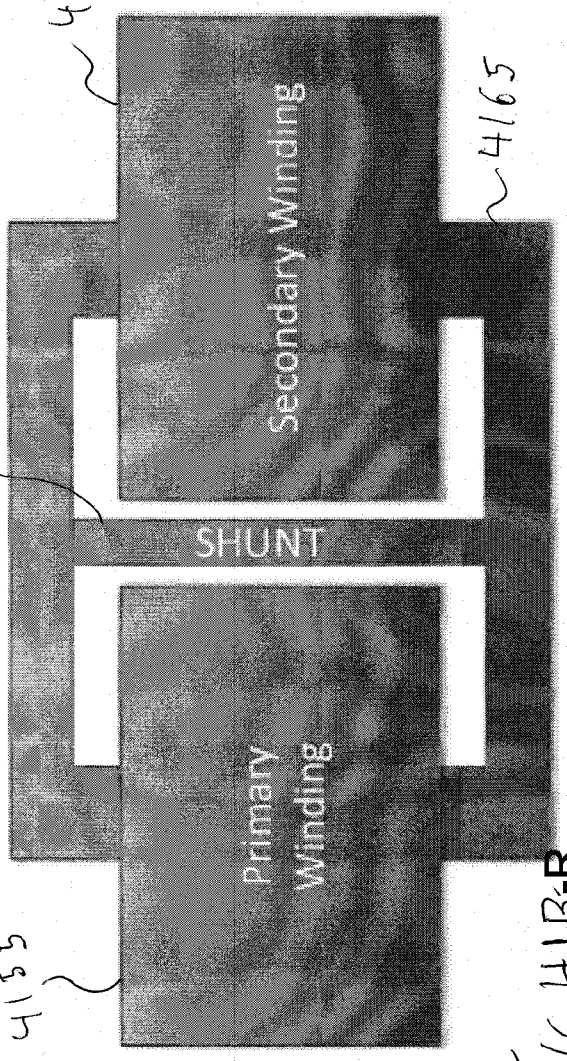


FIG 41B-R

FIG 41C

FIG 42A

FIG 42B-R

Fig 43-R

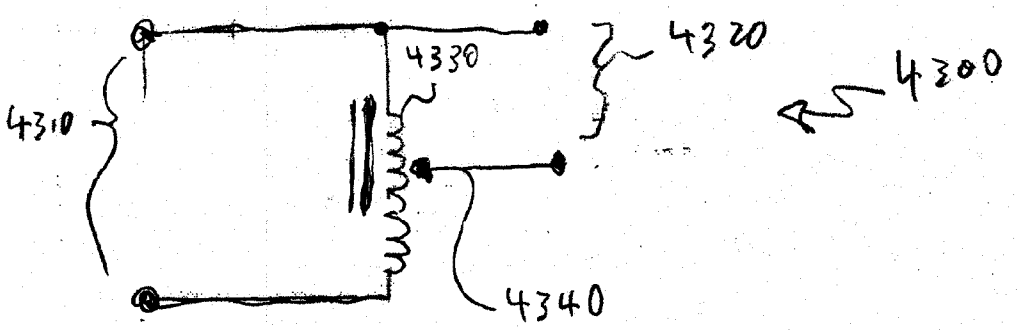
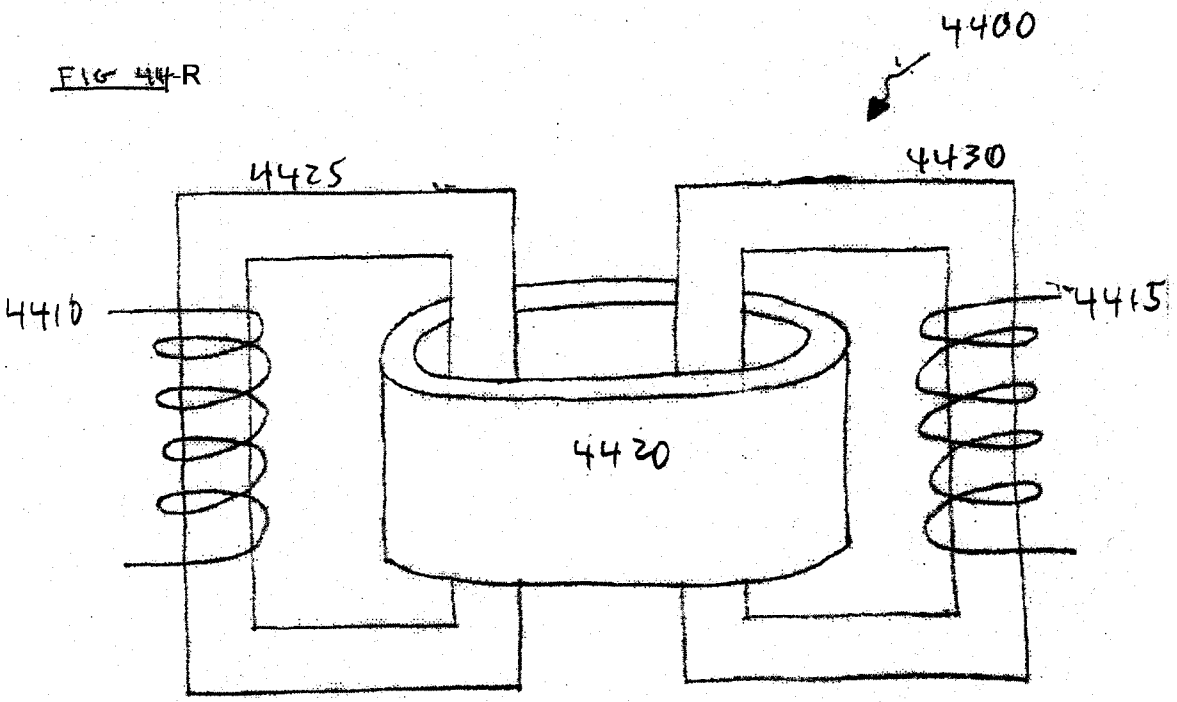


Fig 44-R



First Inventor:
Title:

Attorney Docket No.:

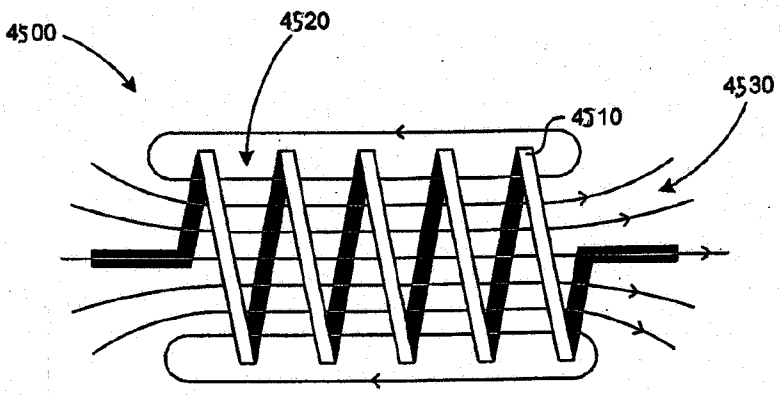


FIG. 45-R

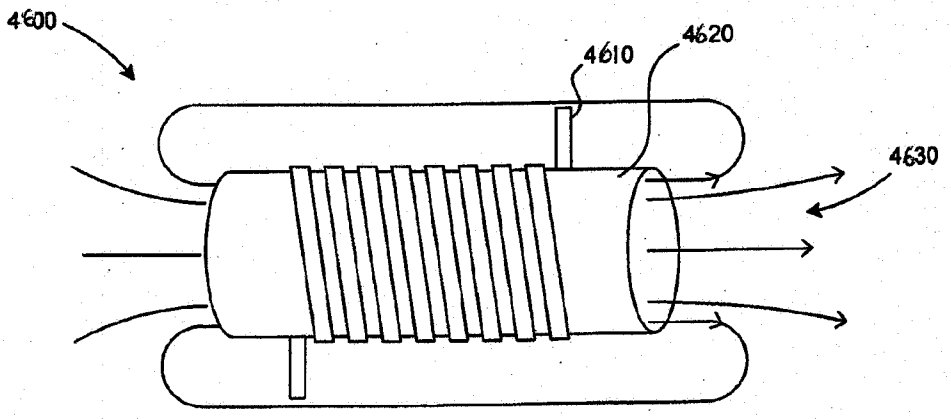


FIG. 46-R

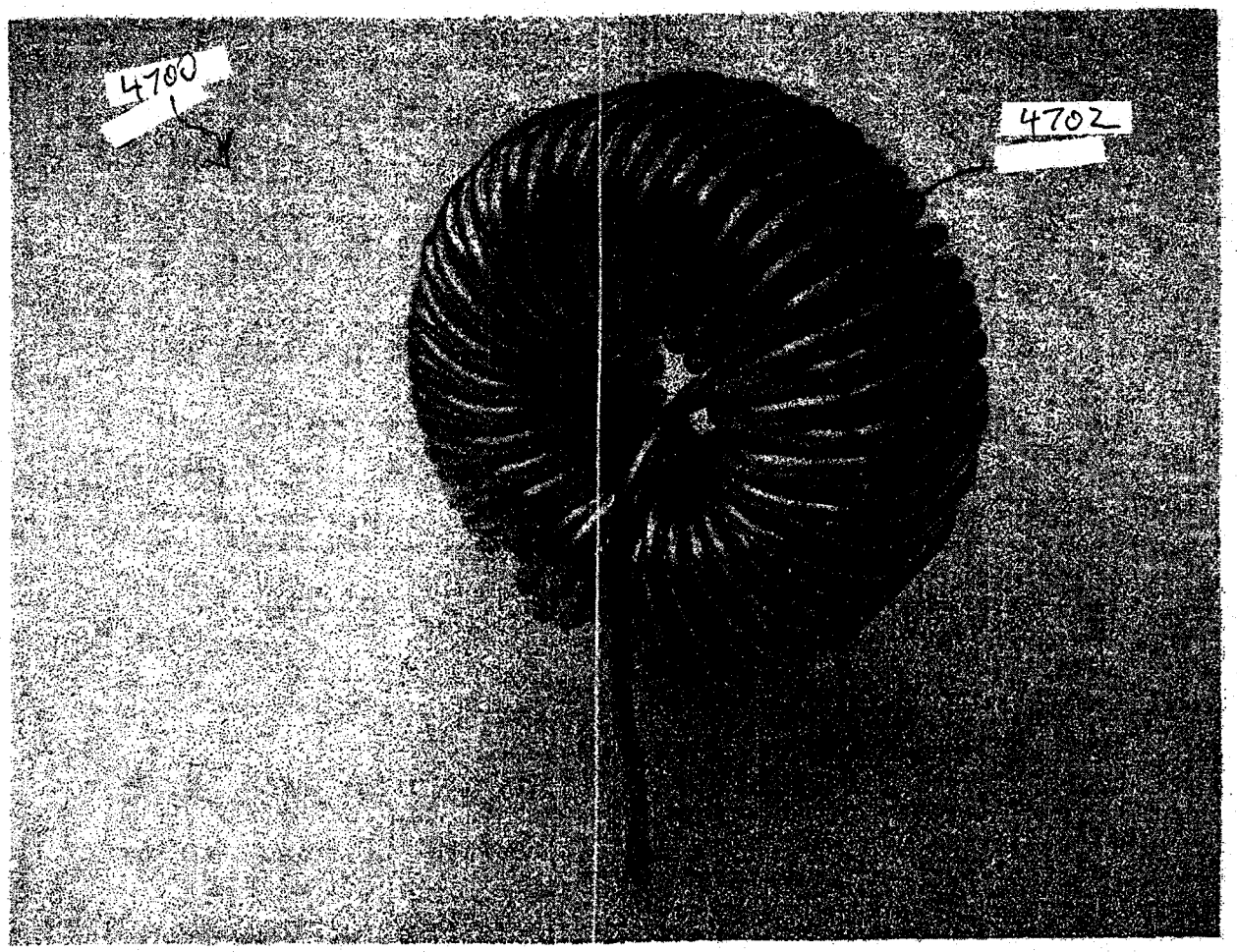


FIG 47R

First Inventor:
Title:

Attorney Docket No.: 7

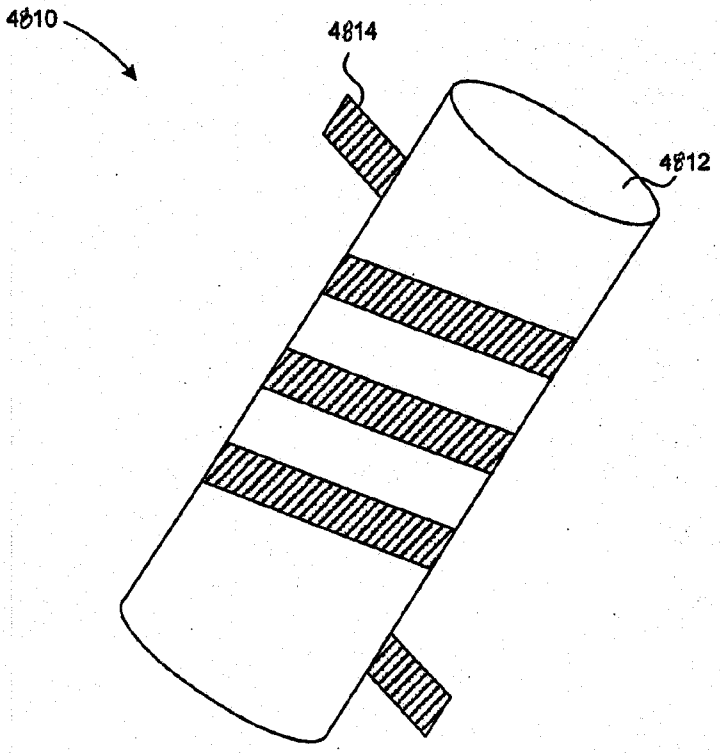


FIG. 48-R

First Inventor:
Title:

Attorney Docket No.:

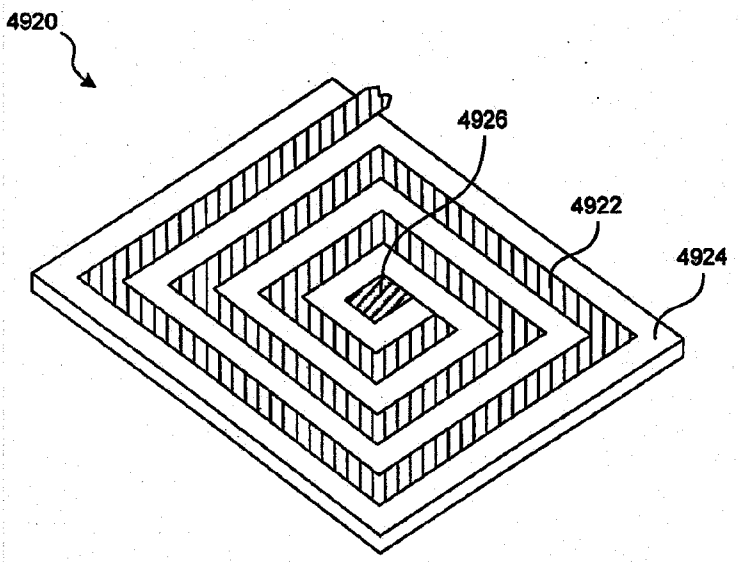


FIG. 49-R

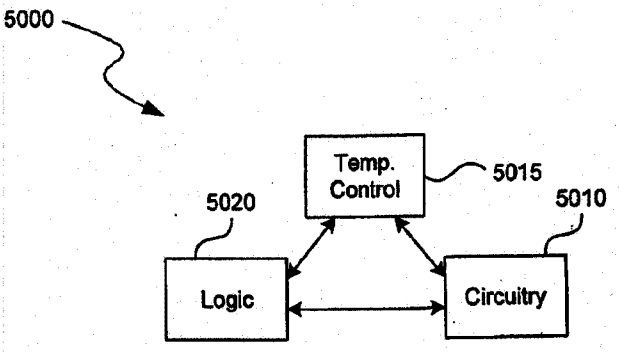


FIG. 50-R

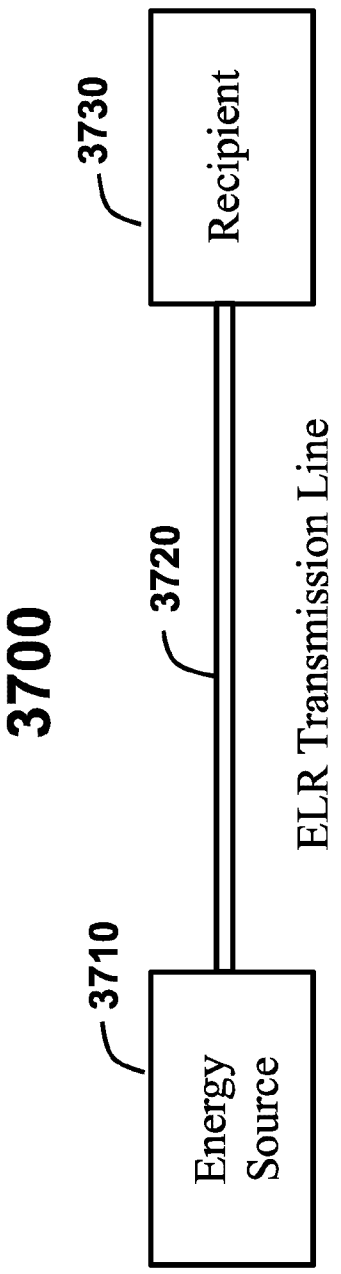


Fig. 37A-S

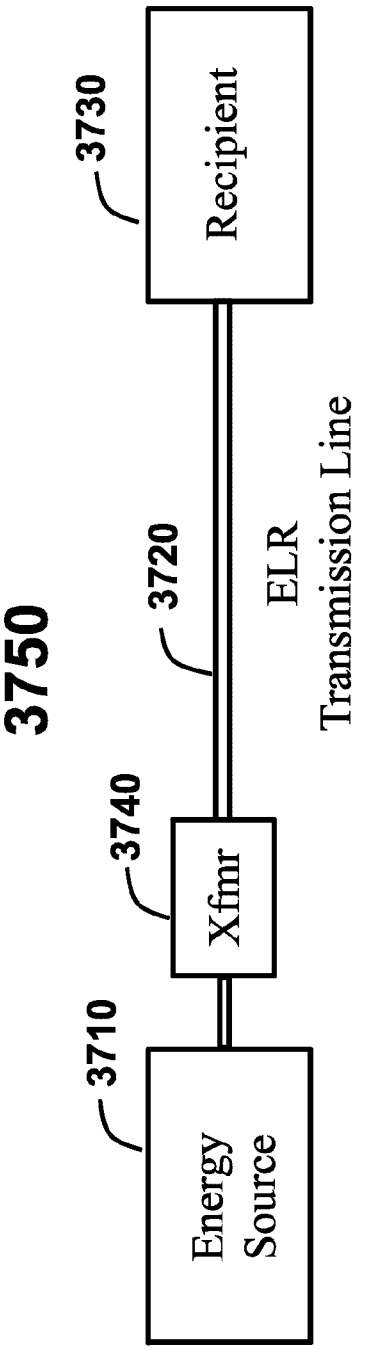


Fig. 37B-S

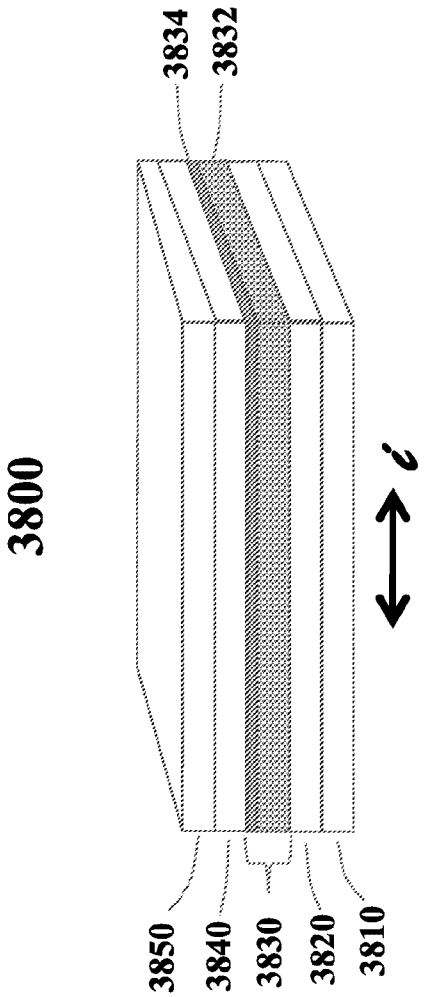


Fig. 38-S

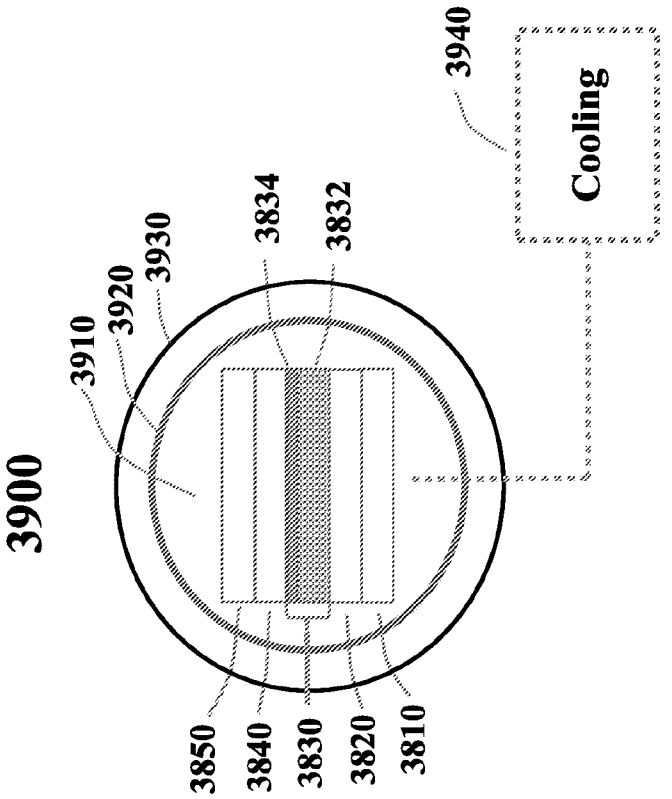

3900
3910
3920
3930
3834
3832
3940
Cooling
3850
3840
3830
3820
3810

Fig. 39-S

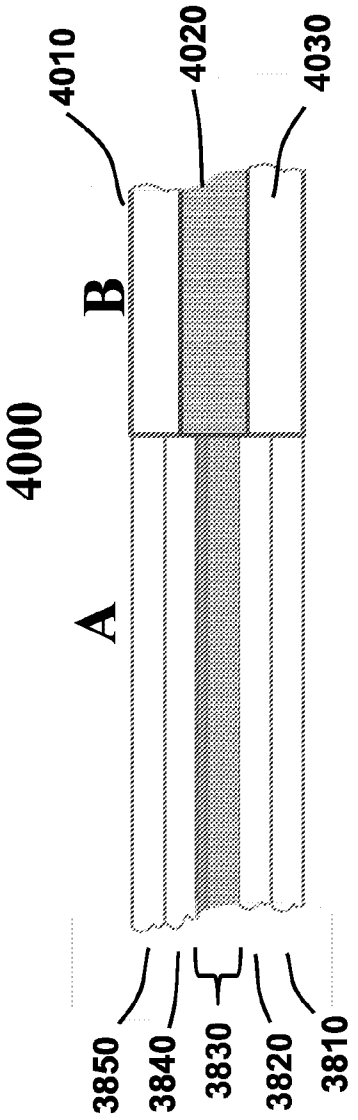


Fig. 40A-S

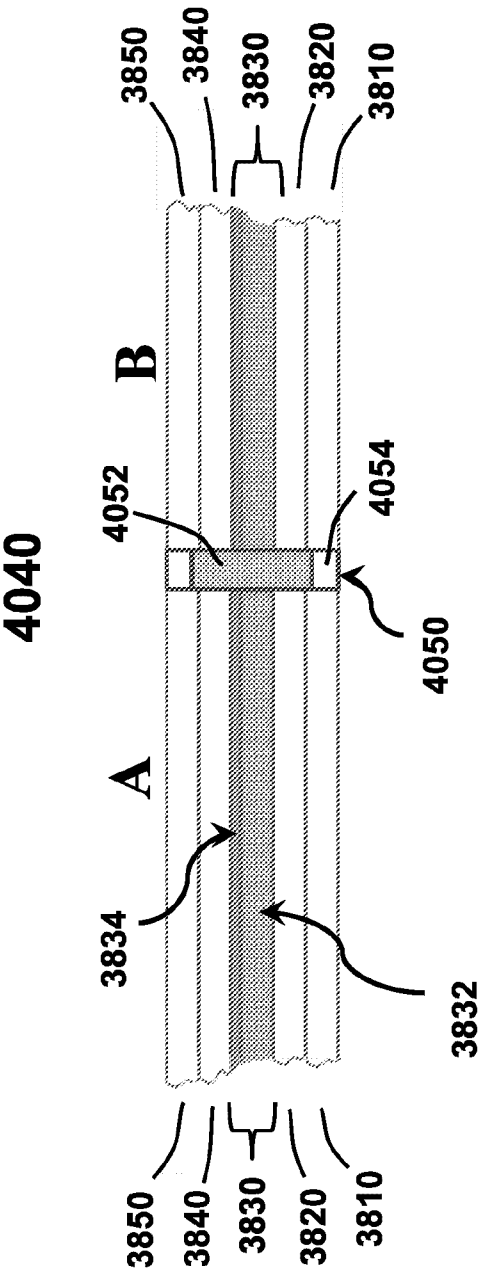


Fig. 40B-S

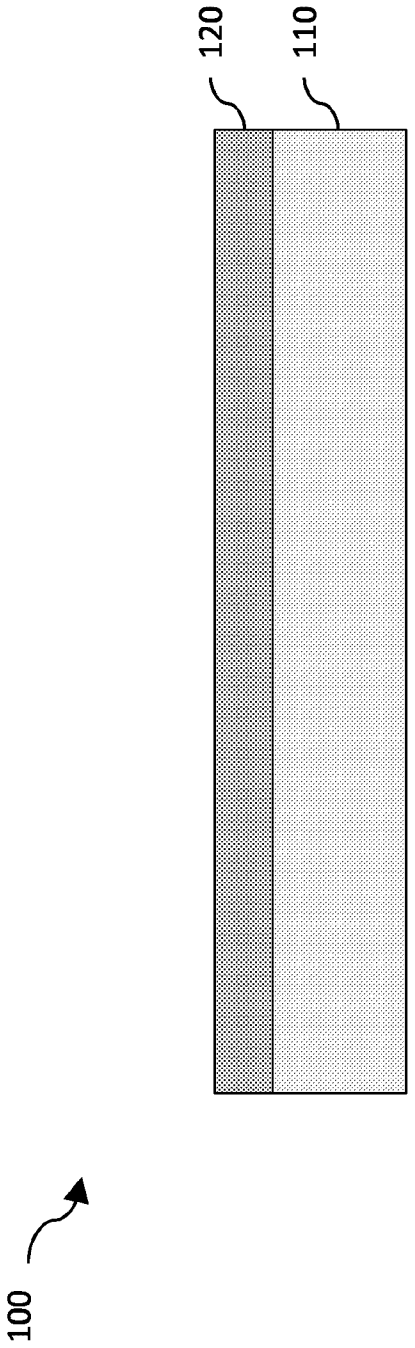


FIG 1-Z

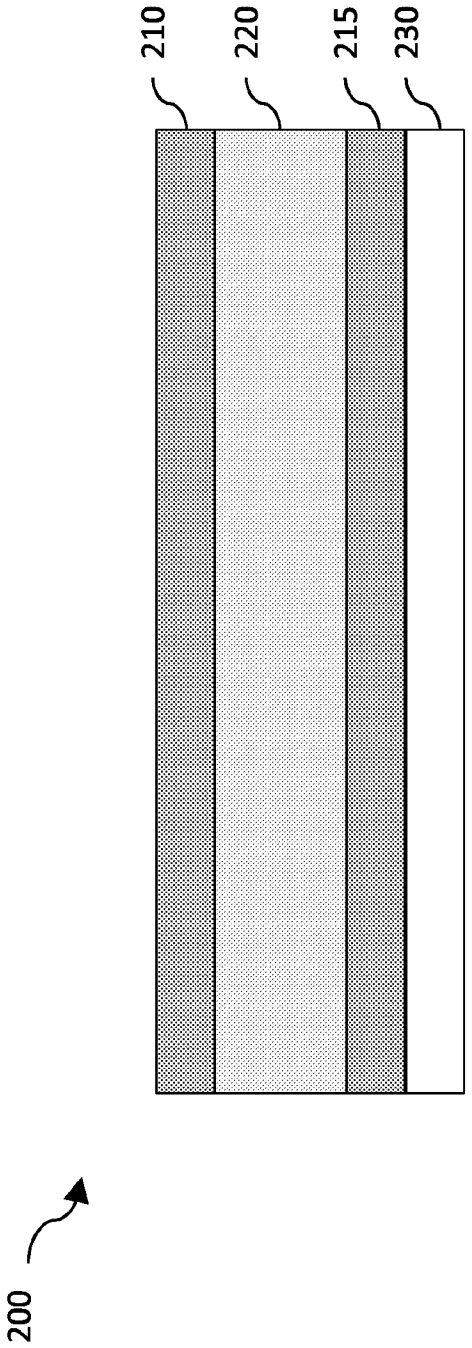


FIG 2-Z

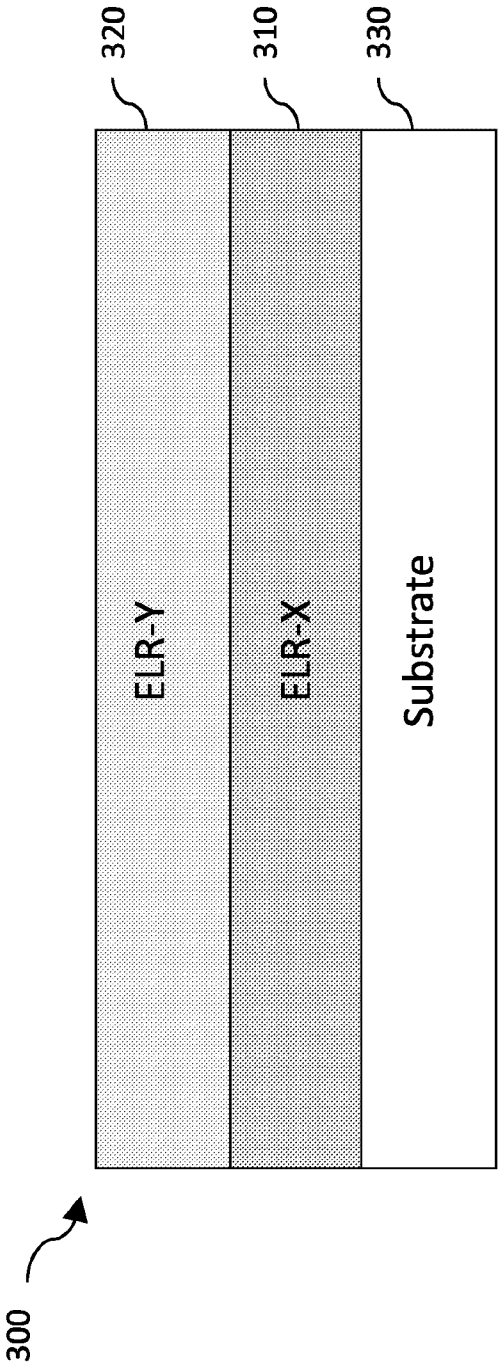


FIG 3-Z

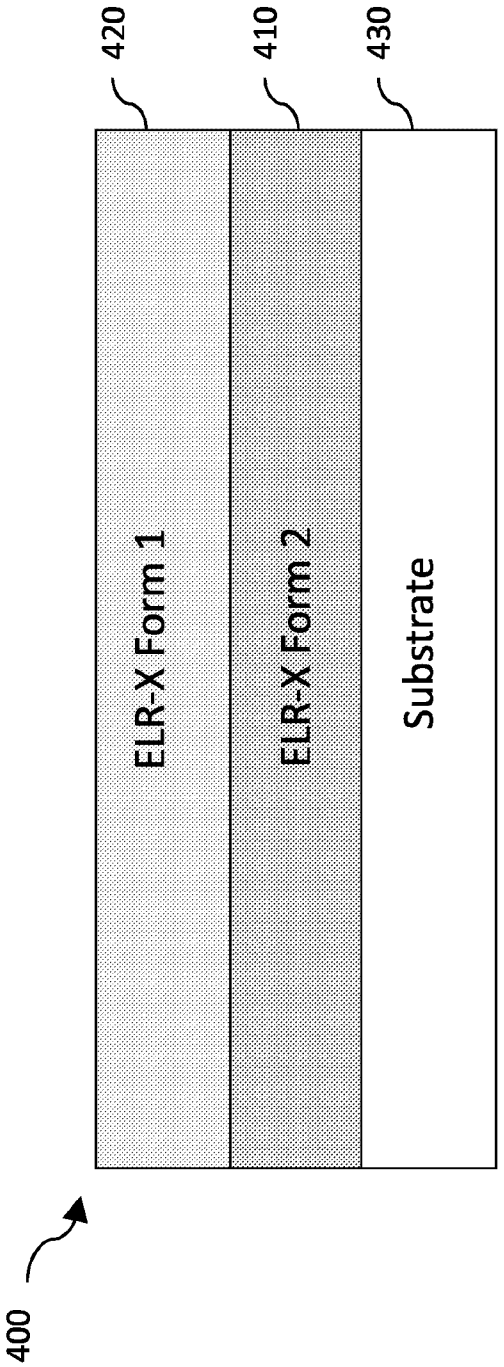


FIG 4-Z

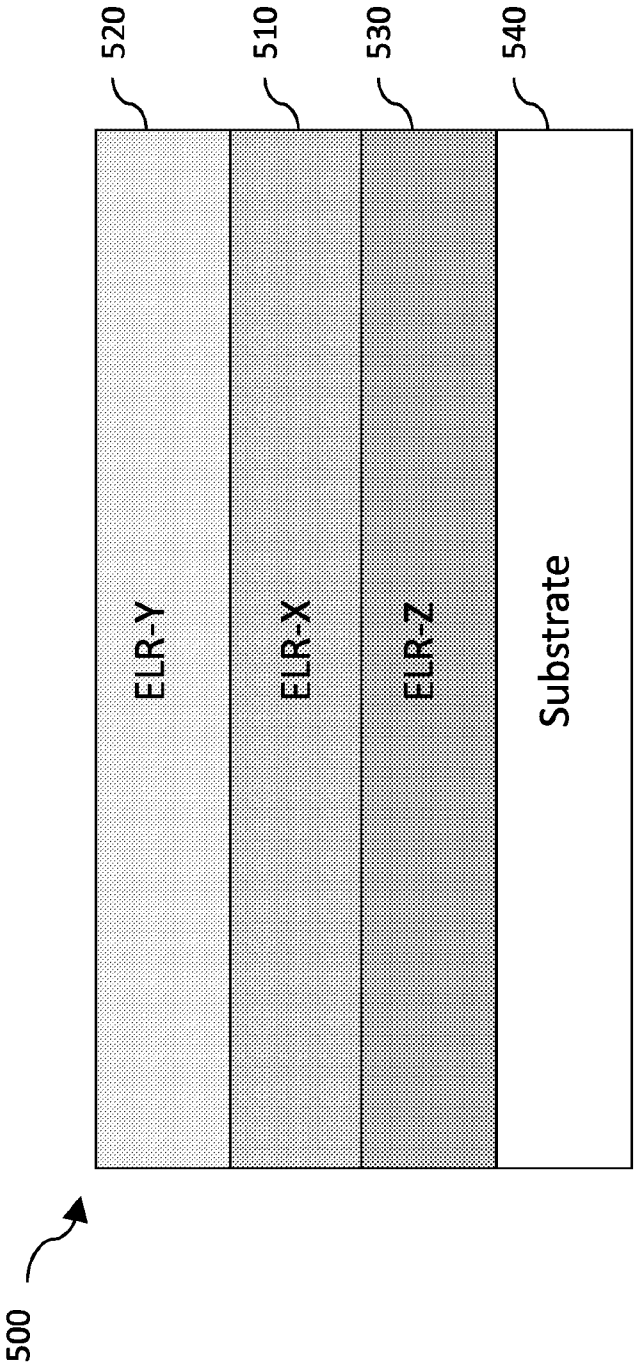


FIG 5-Z

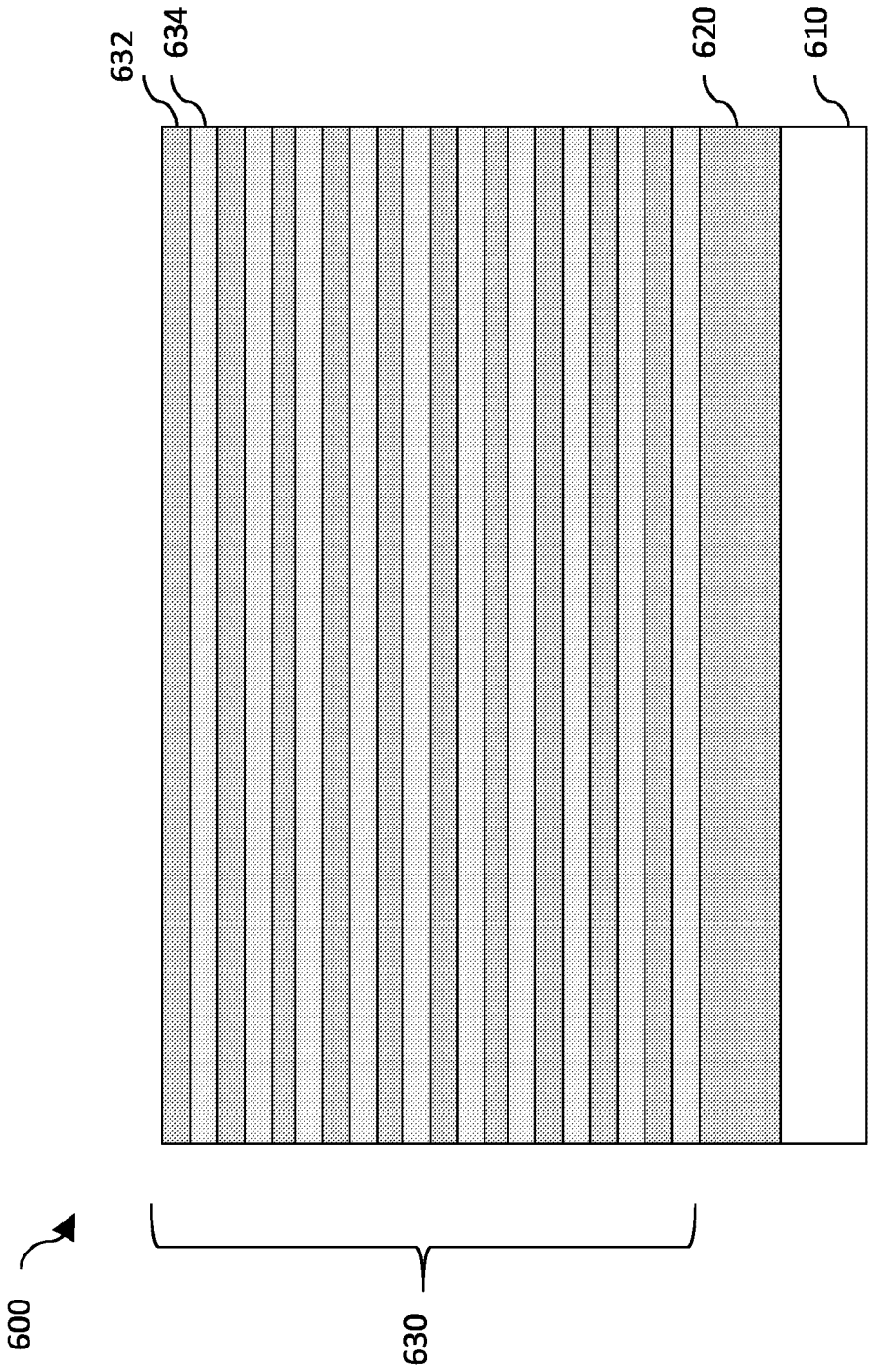


FIG 6-Z

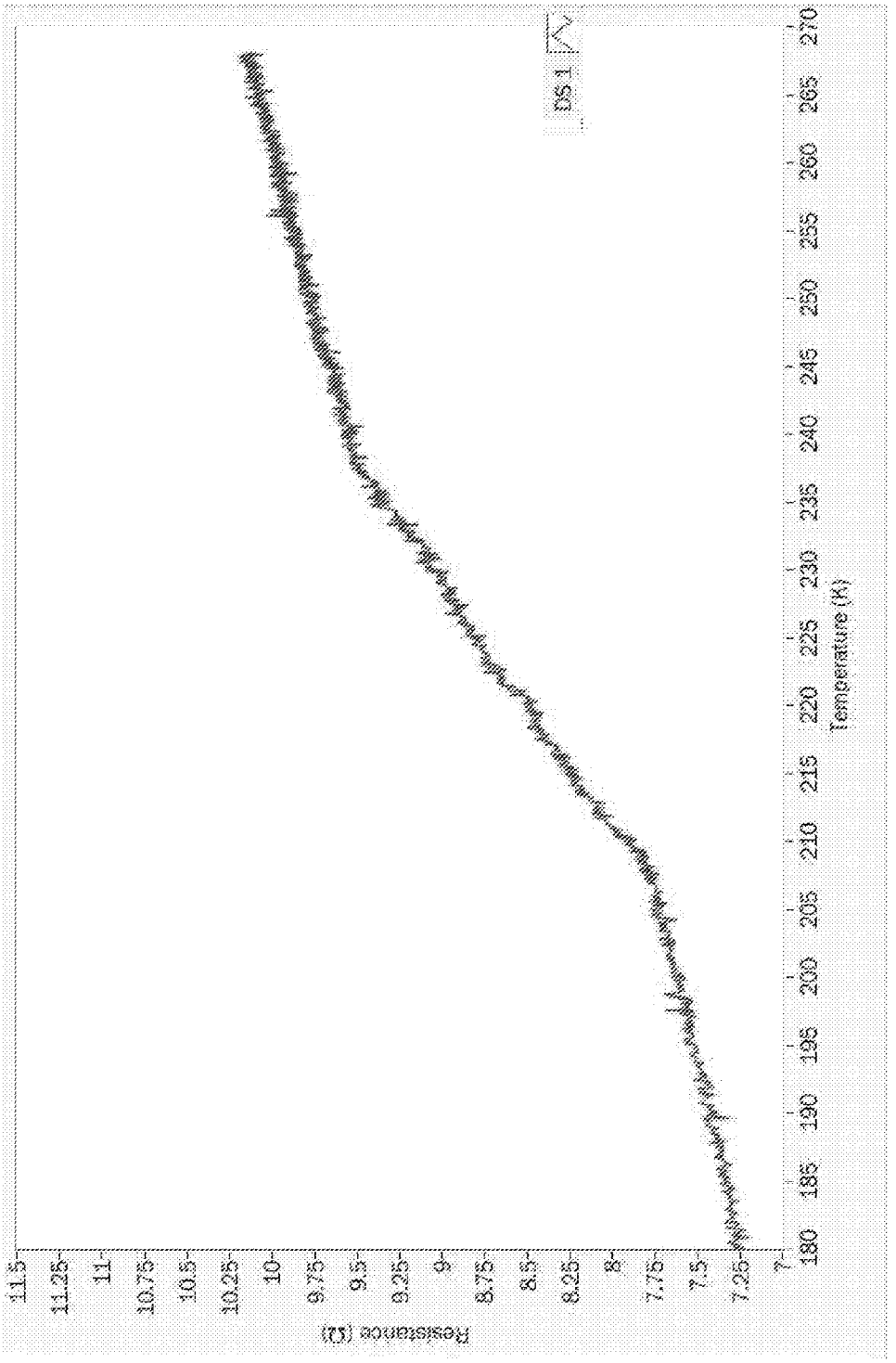

DS 1
Resistance (Ω)
Temperature (K)
11.5
11.25
11
10.75
10.5
10.25
10
9.75
9.5
9.25
9
8.75
8.5
8.25
8
7.75
7.5
7.25
7
180
185
190
195
200
205
210
215
220
225
230
235
240
245
250
255
260
265
270

FIG 7A-Z

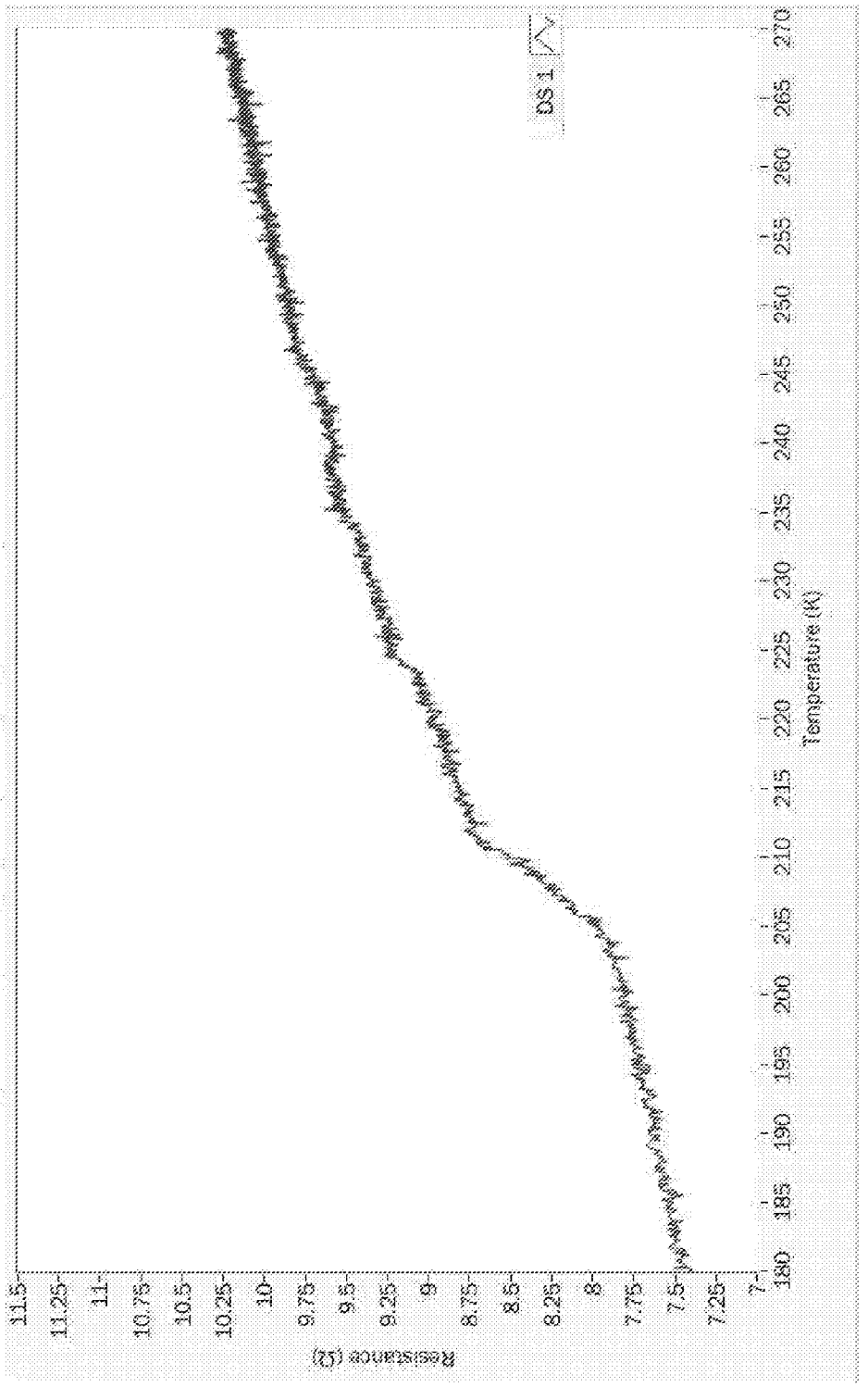

DS 1
Temperature (K)
Resistance (Ω)
11.5
11.25
11
10.75
10.5
10.25
10
9.75
9.5
9.25
9
8.75
8.5
8.25
8
7.75
7.5
7.25
7
180
185
190
195
200
205
210
215
220
225
230
235
240
245
250
255
260
265
270

FIG 7B-Z

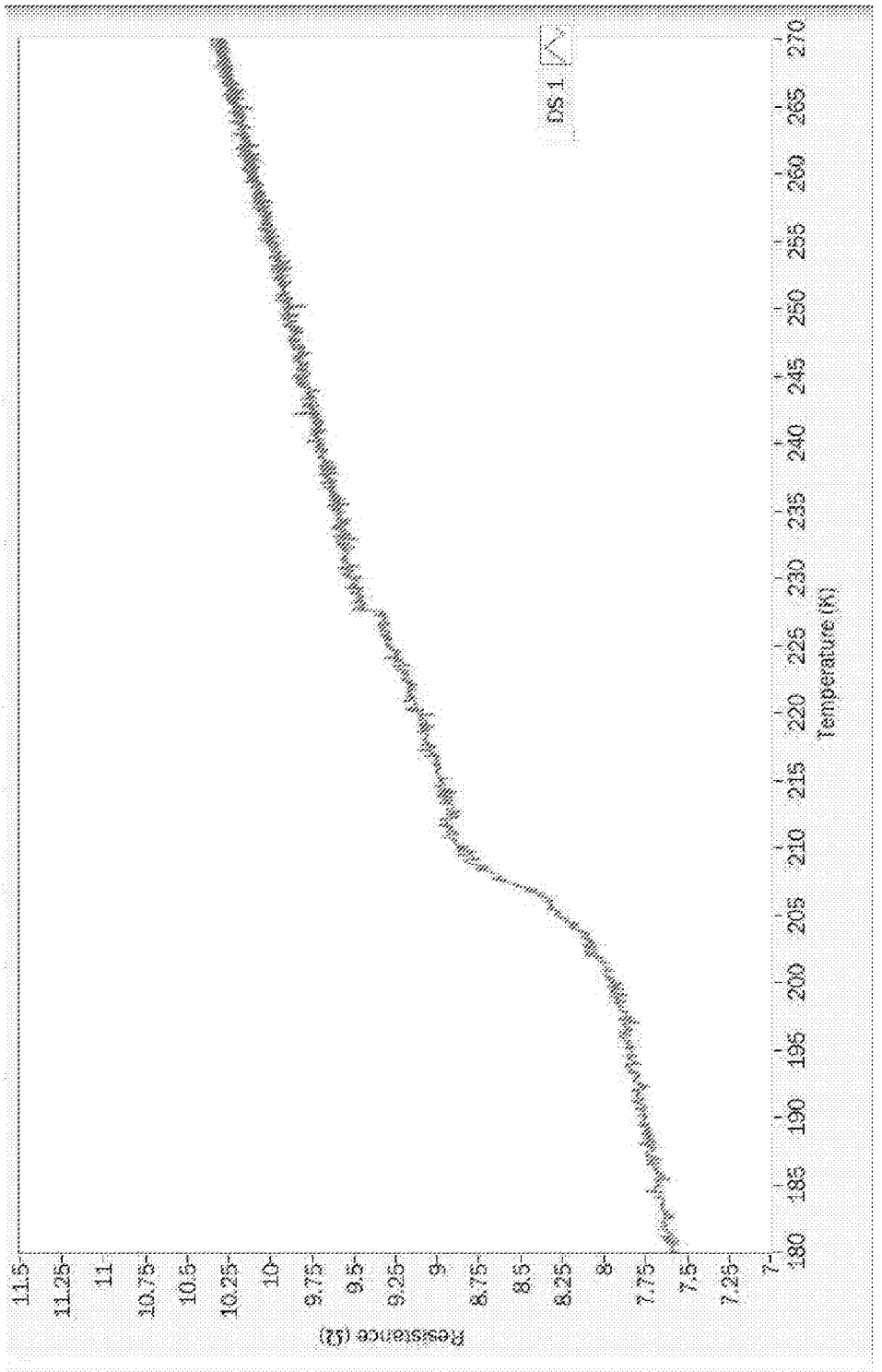

DS 1
Resistance (Ω)
Temperature (K)
11.5
11.25
11
10.75
10.5
10.25
10
9.75
9.5
9.25
9
8.75
8.5
8.25
8
7.75
7.5
7.25
7
180
185
190
195
200
205
210
215
220
225
230
235
240
245
250
255
260
265
270

FIG 7C-Z

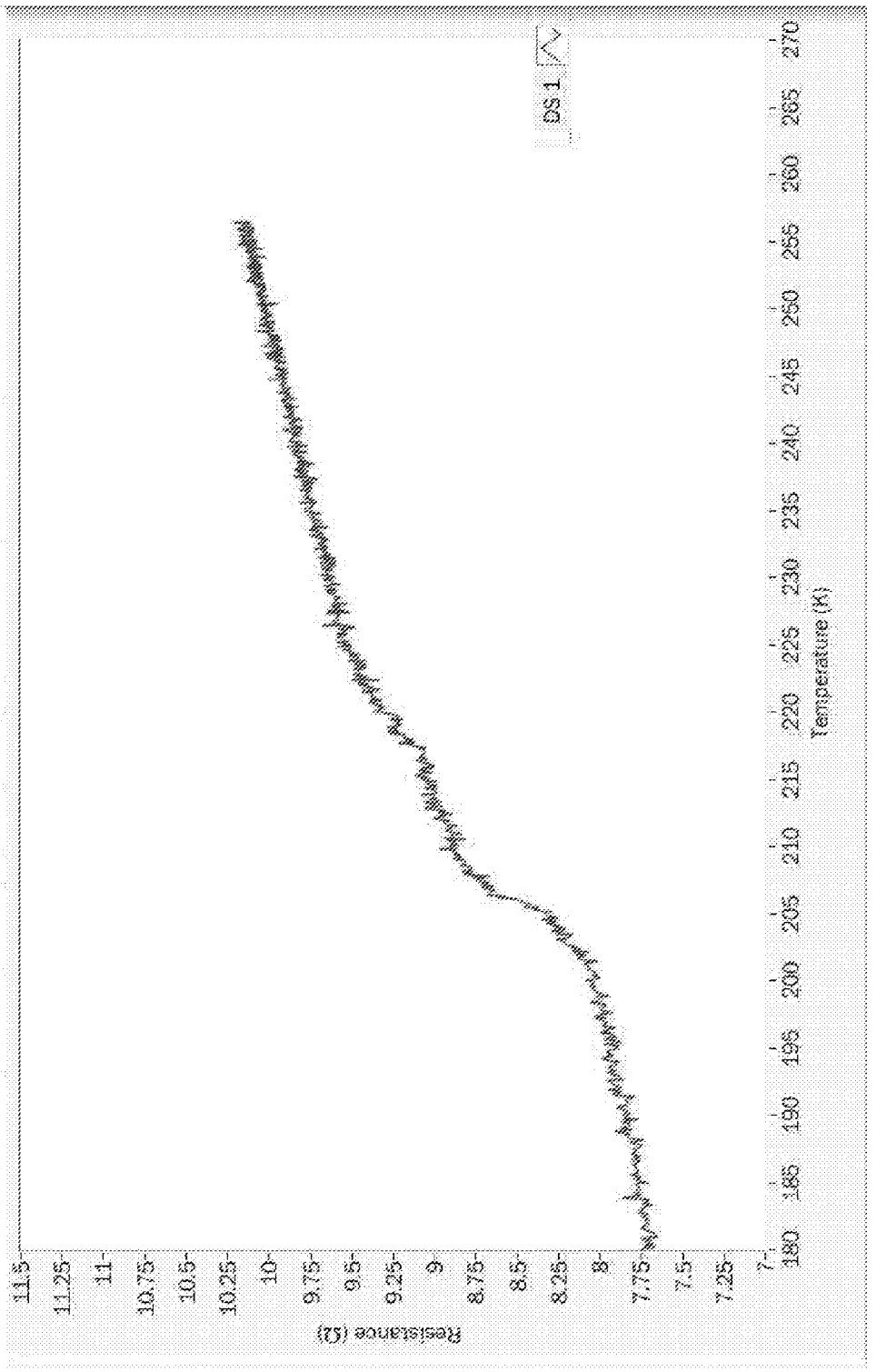

DS 1
Resistance (Ω)
Temperature (K)
11.5
11.25
11
10.75
10.5
10.25
10
9.75
9.5
9.25
9
8.75
8.5
8.25
8
7.75
7.5
7.25
7
180
185
190
195
200
205
210
215
220
225
230
235
240
245
250
255
260
265
270

FIG 7D-Z

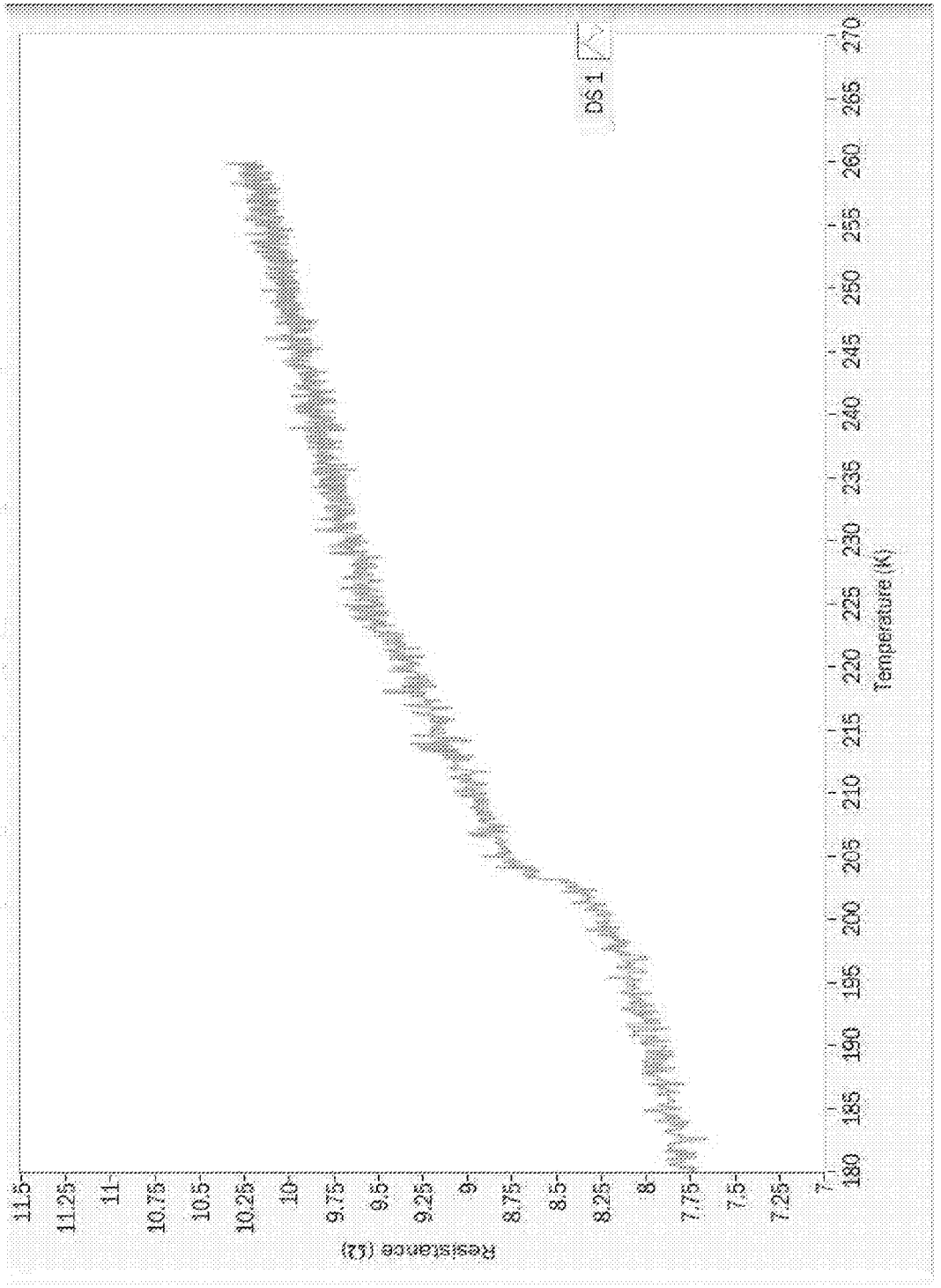

DS1
Resistance (Ω)
Temperature (K)
11.5
11.25
11
10.75
10.5
10.25
10
9.75
9.5
9.25
9
8.75
8.5
8.25
8
7.75
7.5
7.25
7
180
185
190
195
200
205
210
215
220
225
230
235
240
245
250
255
260
265
270

FIG 7E-Z

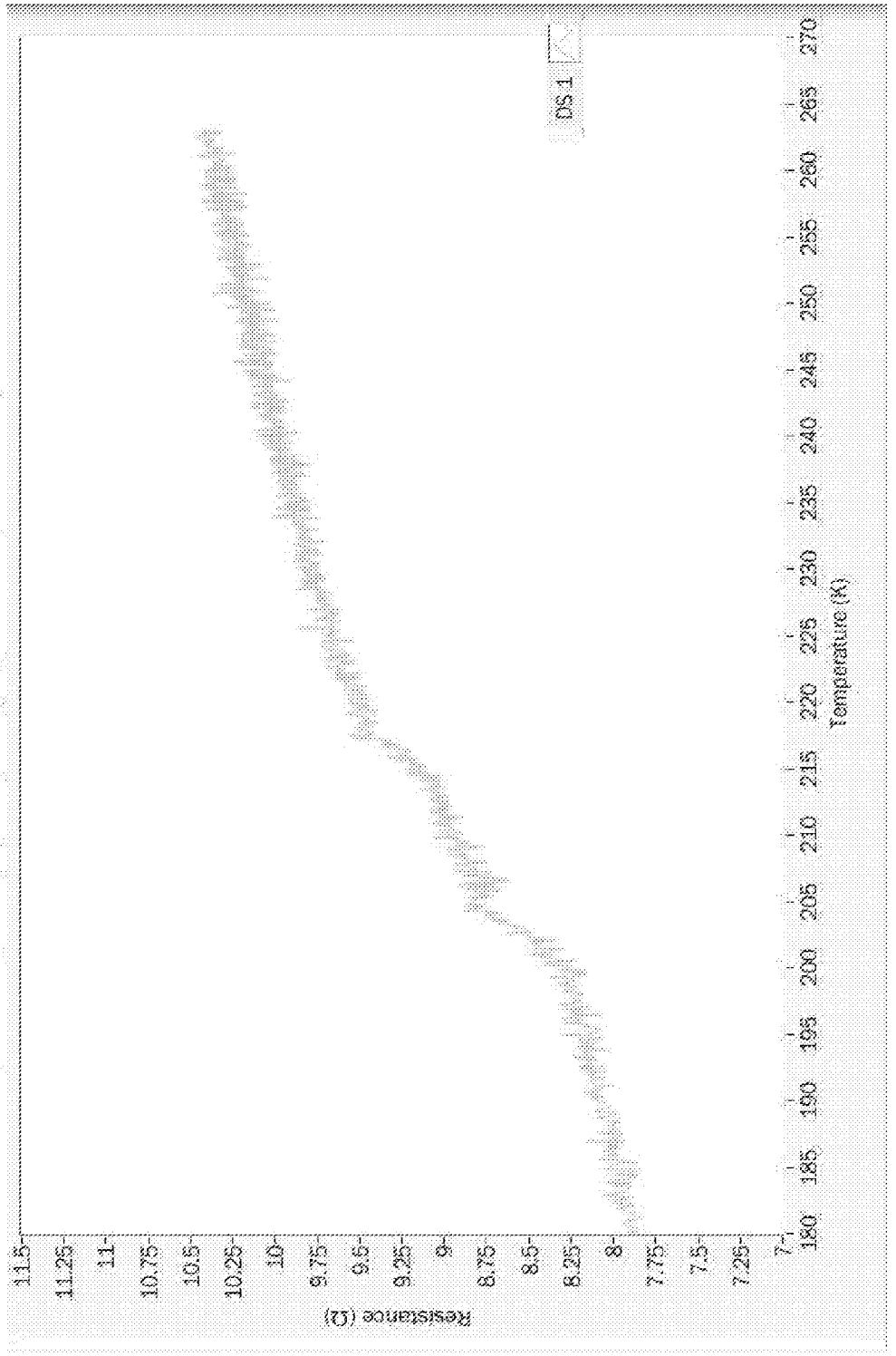

DS 1
Resistance (Ω)
Temperature (K)
11.5
11.25
11
10.75
10.5
10.25
10
9.75
9.5
9.25
9
8.75
8.5
8.25
8
7.75
7.5
7.25
7
180
185
190
195
200
205
210
215
220
225
230
235
240
245
250
255
260
265
270

FIG 7F-Z

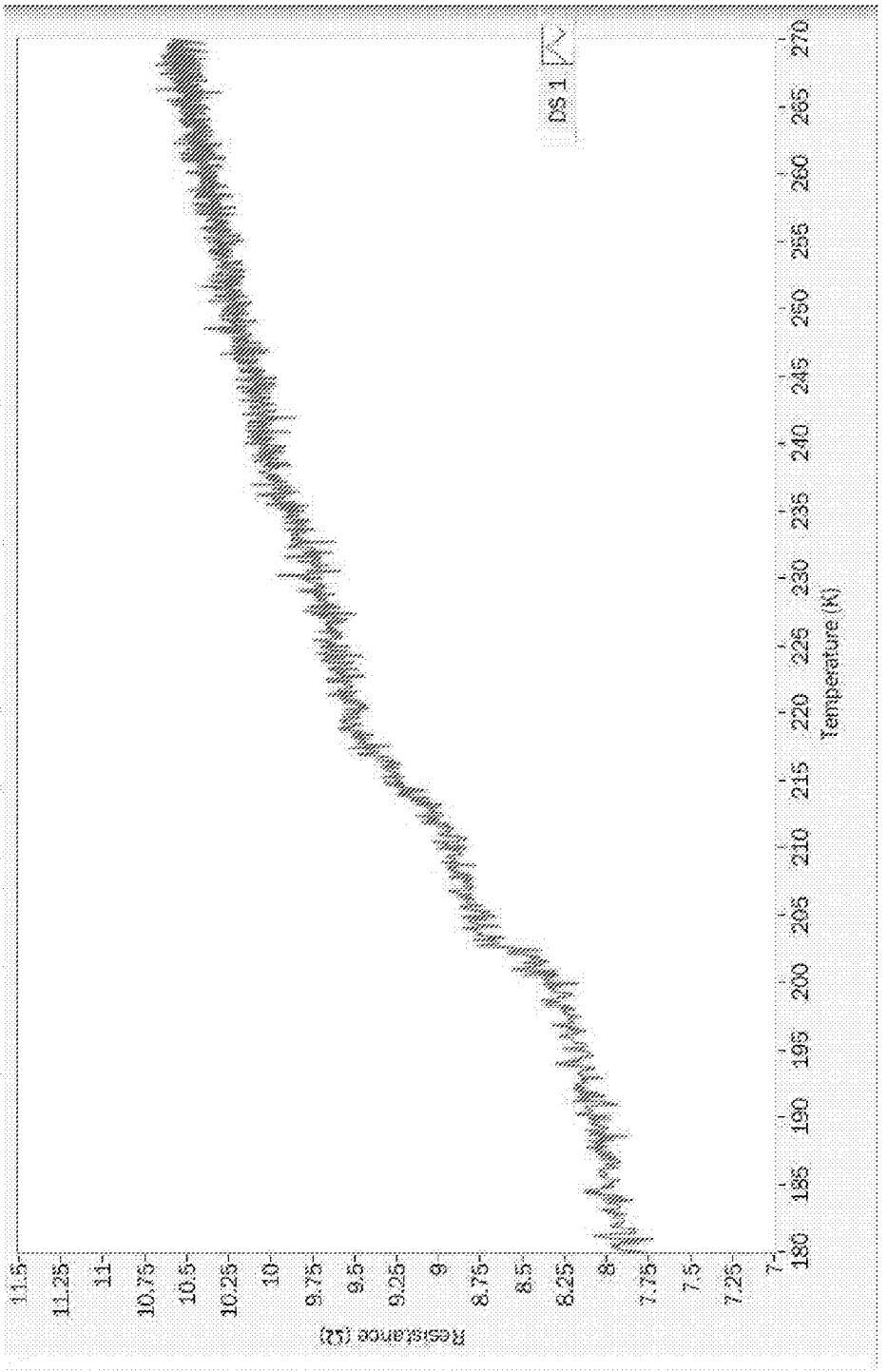


FIG 7G-Z

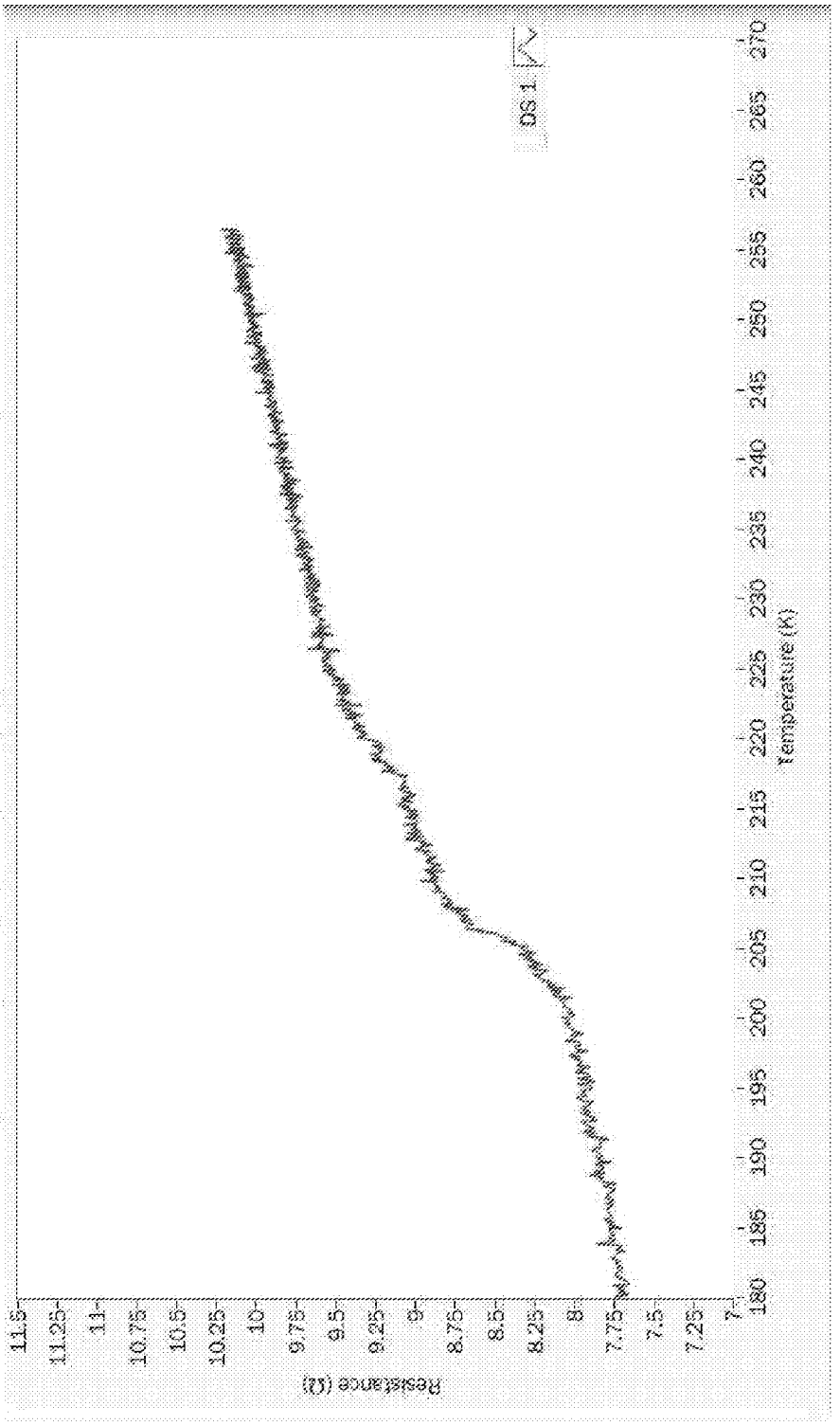

DS 1
Resistance (Ω)
Temperature (K)
11.5
11.25
11
10.75
10.5
10.25
10
9.75
9.5
9.25
9
8.75
8.5
8.25
8
7.75
7.5
7.25
7
180
185
190
195
200
205
210
215
220
225
230
235
240
245
250
255
260
265
270

FIG 7H-Z

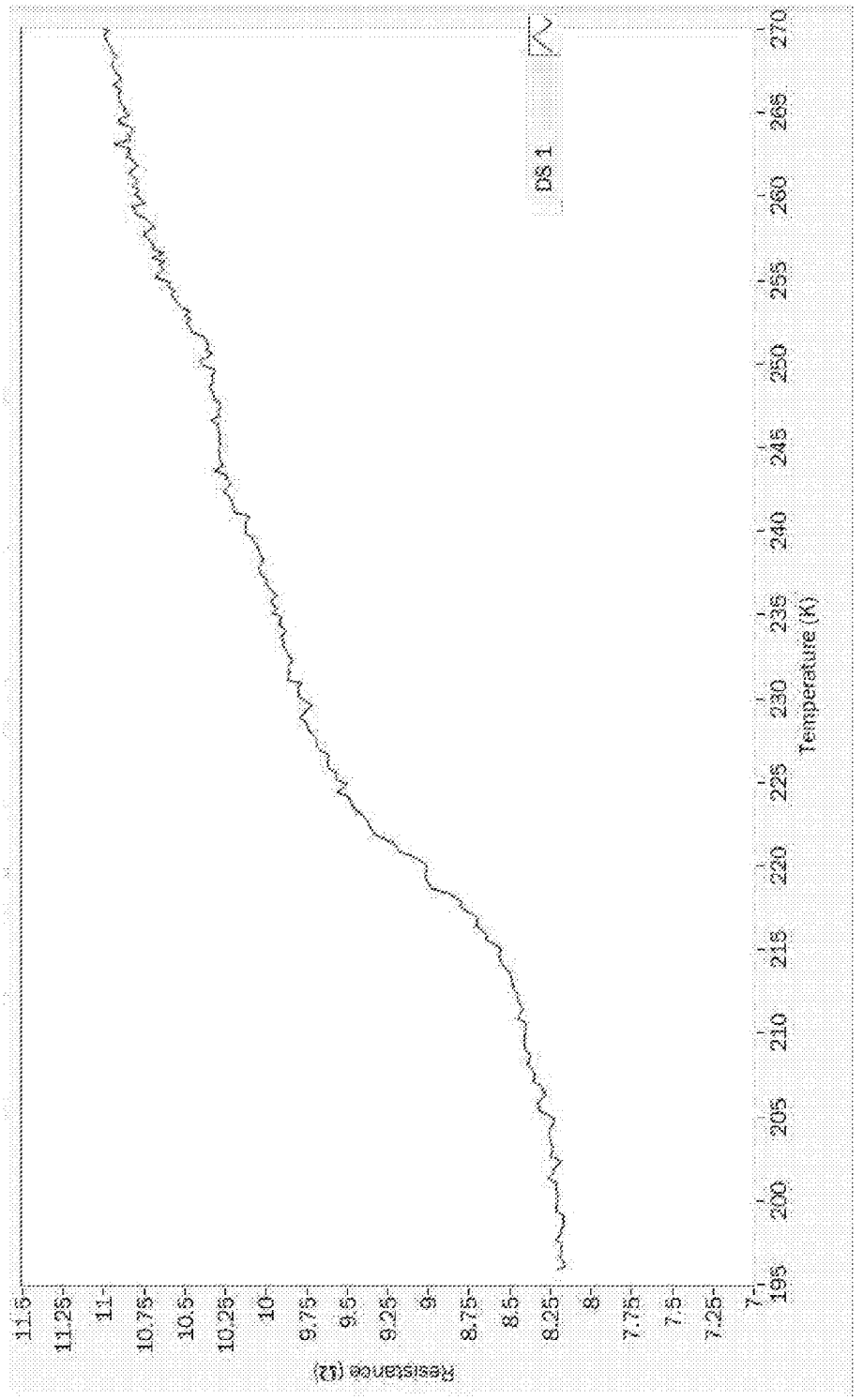
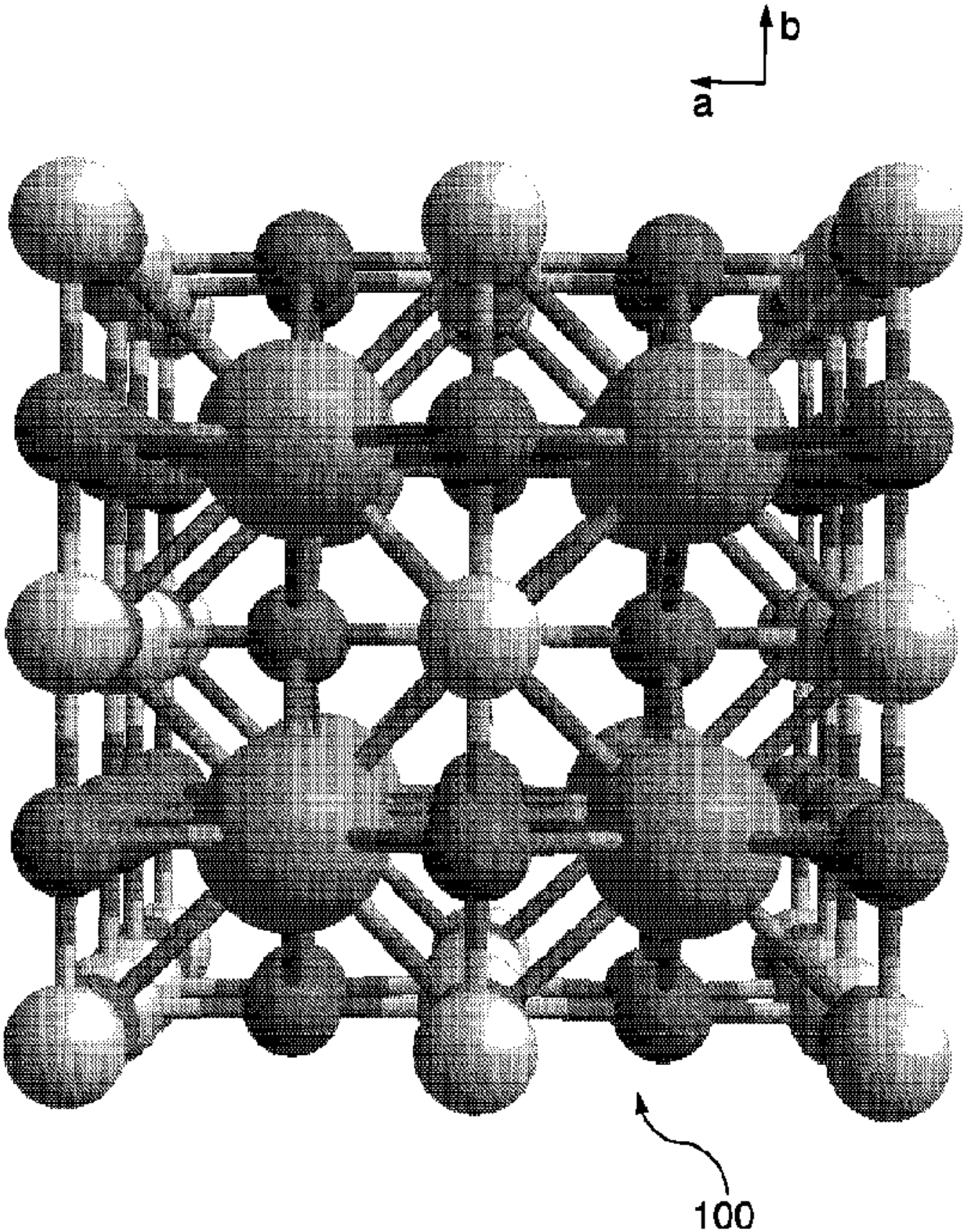

DS 1
Resistance (Ω)
Temperature (K)
11.5
11.25
11
10.75
10.5
10.25
10
9.75
9.5
9.25
9
8.75
8.5
8.25
8
7.75
7.5
7.25
7
195
200
205
210
215
220
225
230
235
240
245
250
255
260
265
270

FIG 7I-Z


b
a
100